Engine Noise Reduction Technologies And Strategies for Commercial Applications

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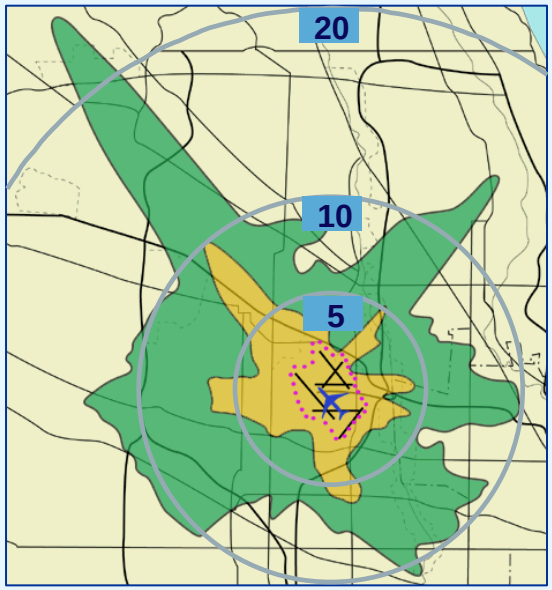
Thanks to Drs. James Bridges, Edmane Envia, Daniel Sutliff and Joe Grady

Outline

- Introduction to Engine Noise Research at NASA
- Fan Noise
- Jet Noise
- Engine Noise and Future Opportunities

Introduction to Engine Noise Research at NASA

Technology Benefit: Reduced Noise Exposure



1997 Baseline

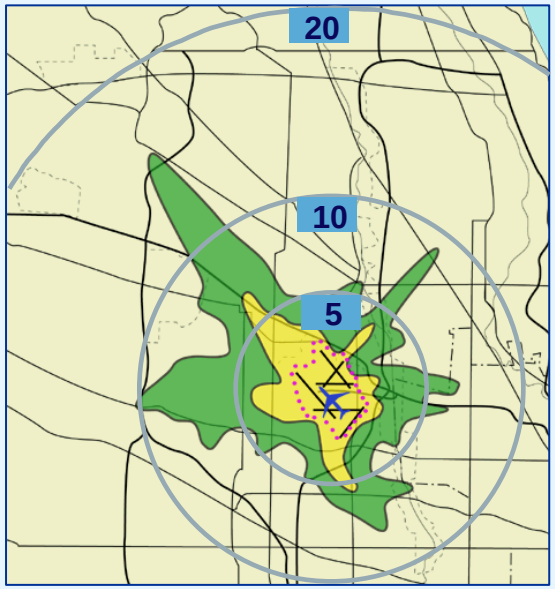
Key

55 dB

65 dB

Airport

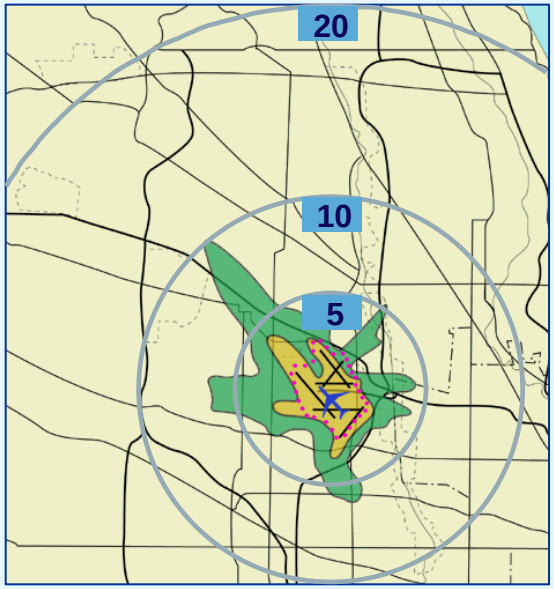
0 Miles 10



AST Technology Benefit

(Advanced Subsonic Technology)

- 5 dB Reduction (TRL 6)
- Doesn't meet public expectations
- Constrained growth



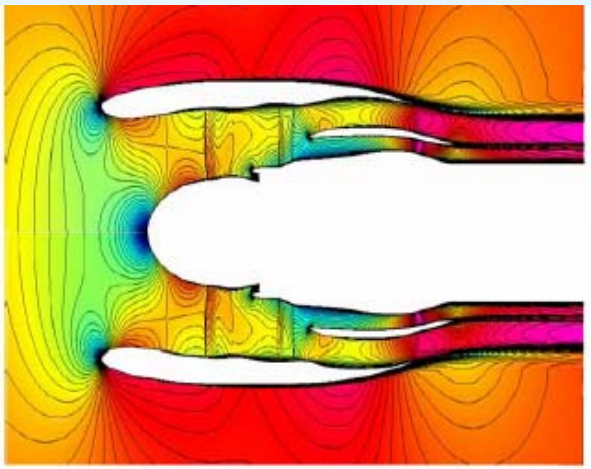
QAT Technology Benefit

(Quiet Aircraft Technology)

- 10 dB reduction
- 65 dB contour is within airport
- Enables projected air travel growth
- Reduces community noise impact

Quiet Aircraft Technology (QAT) Sub-Projects

Airframe
Landing Gear
High-lift system
Integrated Propulsion



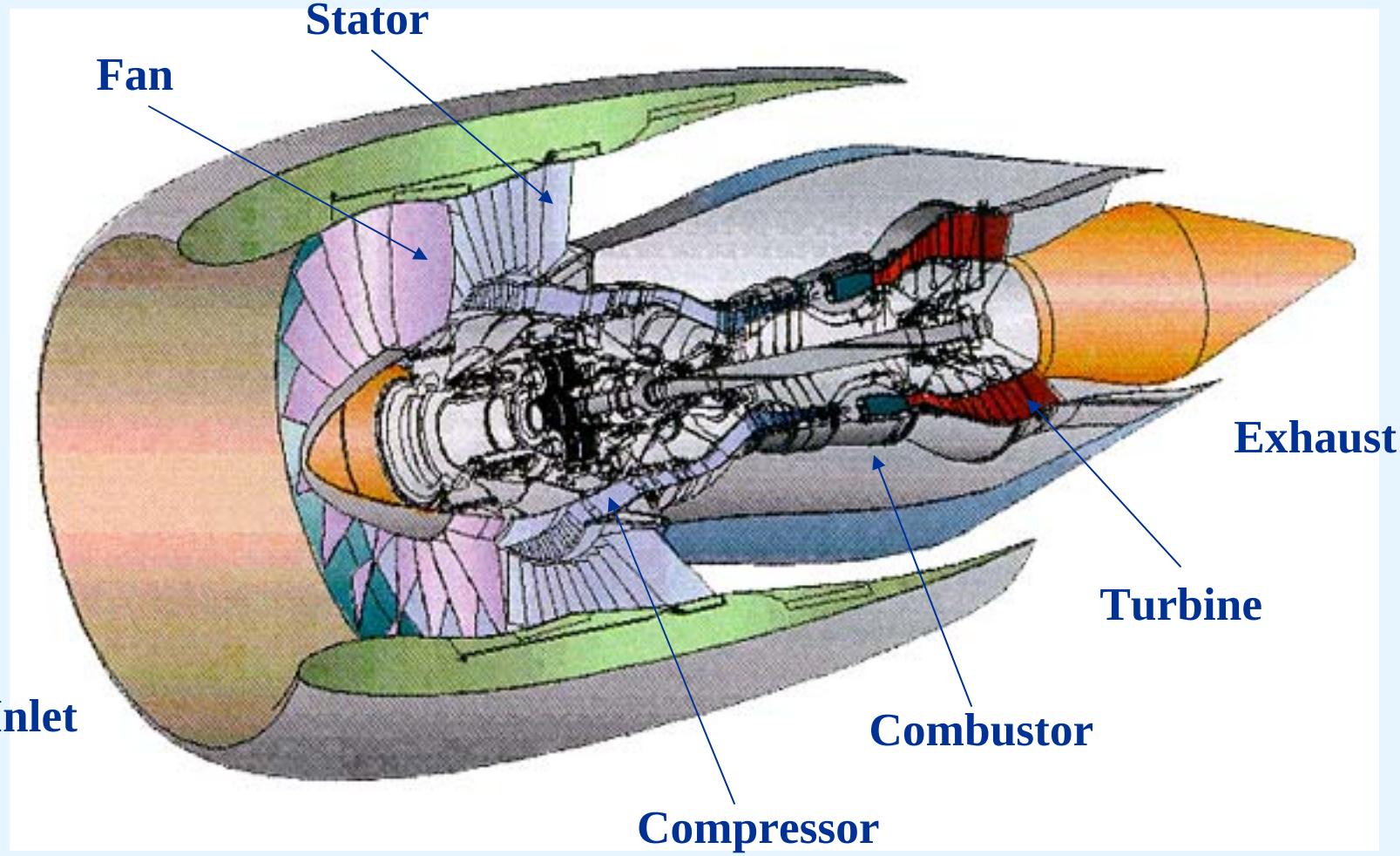
Engine
Fan
Jet
Core

Aircraft operations

Aircraft Goal: 10 dB Quieter than 1997 Technology

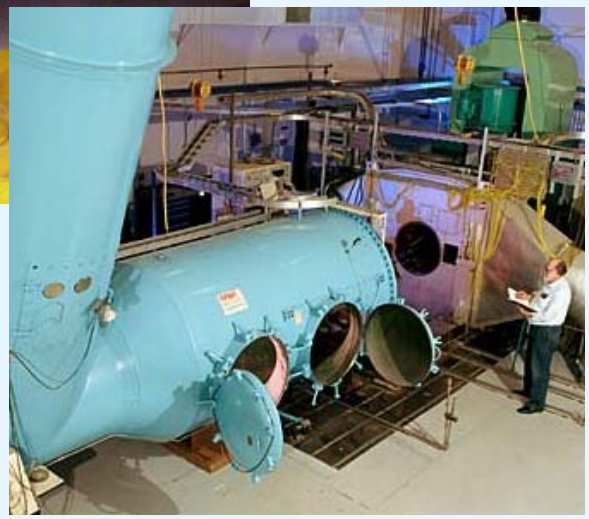
Engine Noise Sources

(P&W PW8000 Engine, Conceptual)

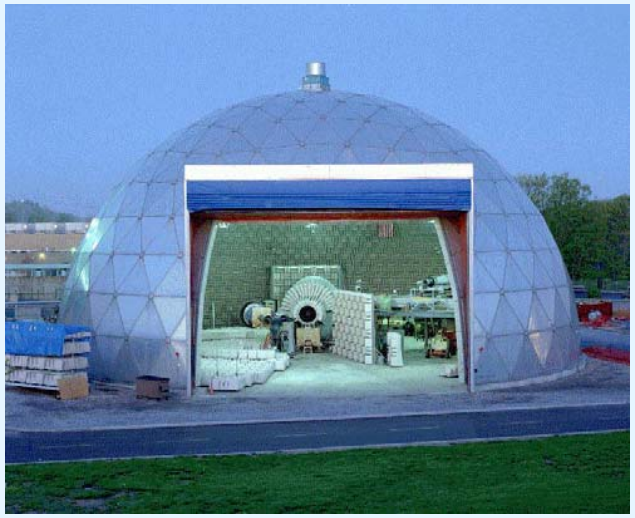


Major Engine Noise Test Facilities at NASA Glenn

9x15 Wind Tunnel



W8 Fan Rig



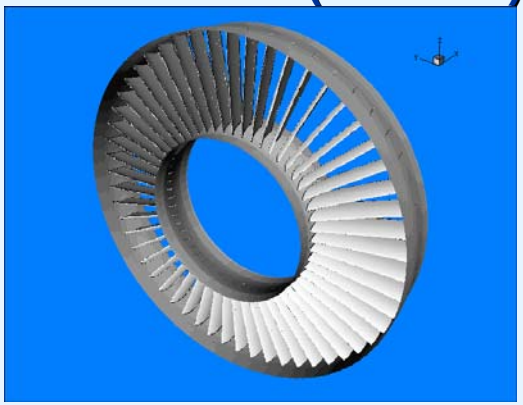
AeroAcoustic Propulsion Lab

Test Facilities Provide Component-Level Noise Assessments

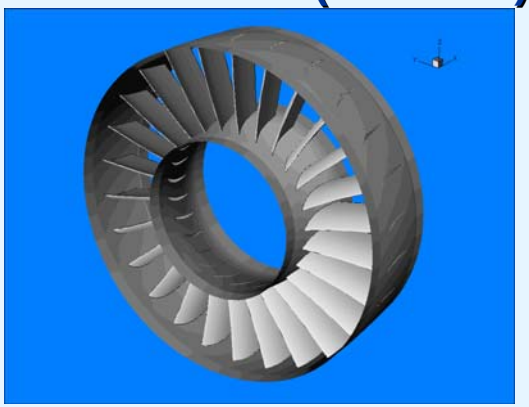
Fan Noise

Fan Noise Prediction (LINFLUX Code)

Cut-Off Stator (54-Vanes)



Cut-On Stator (26-Vanes)



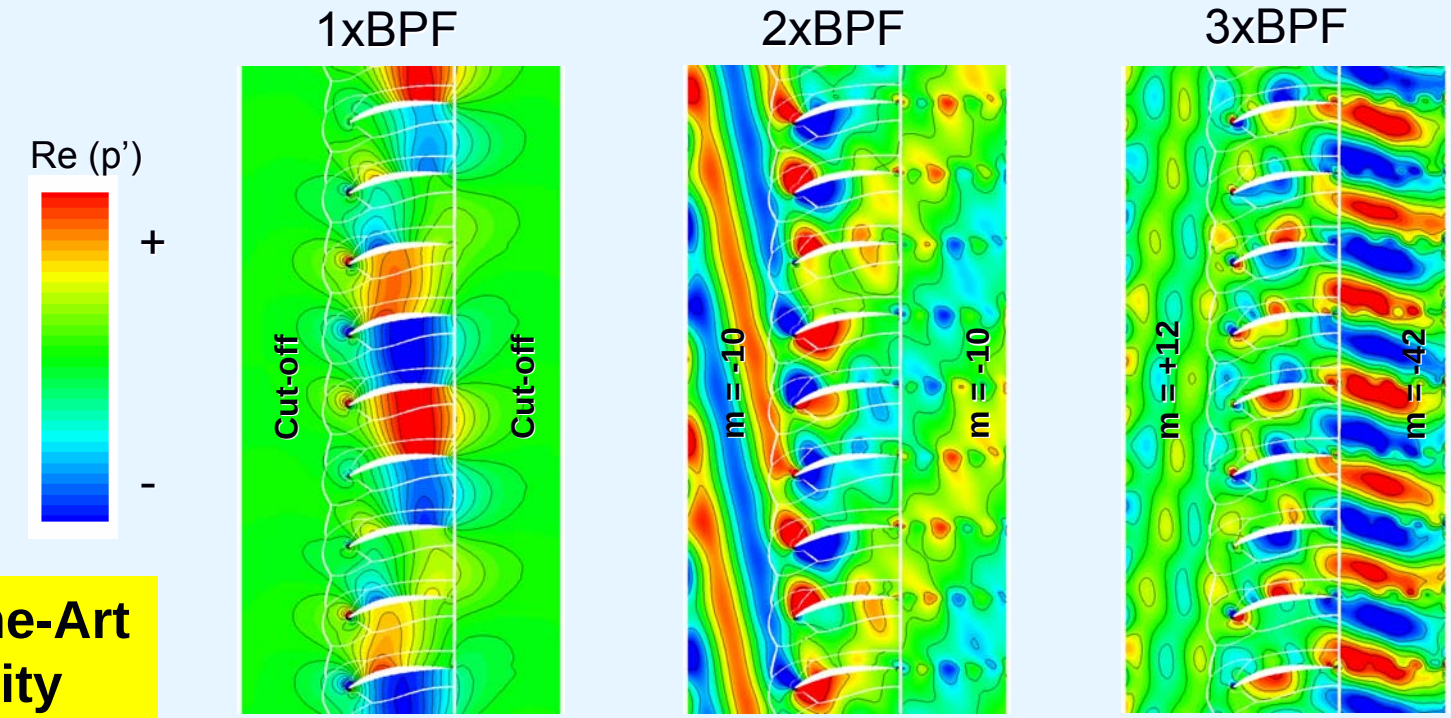
Downstream Tone Levels
Prediction Data

Cut-Off Stator (2xBPF)			Cut-On Stator (1xBPF)		
Mode: (m,n)	Power (dB)		Mode: (m,n)	Power (dB)	
(-10,0)	113	111	(-4,0)	124	124
(-10,1)	100	97	(-4,1)	120	120
(-10,2)	101	103			
(-10,3)	102	98			
Total	114	112	Total	125	125

Fan Noise Computational Aero Acoustics (BASS Code)

Goal: Develop a 3D time-accurate nonlinear fan noise prediction code.

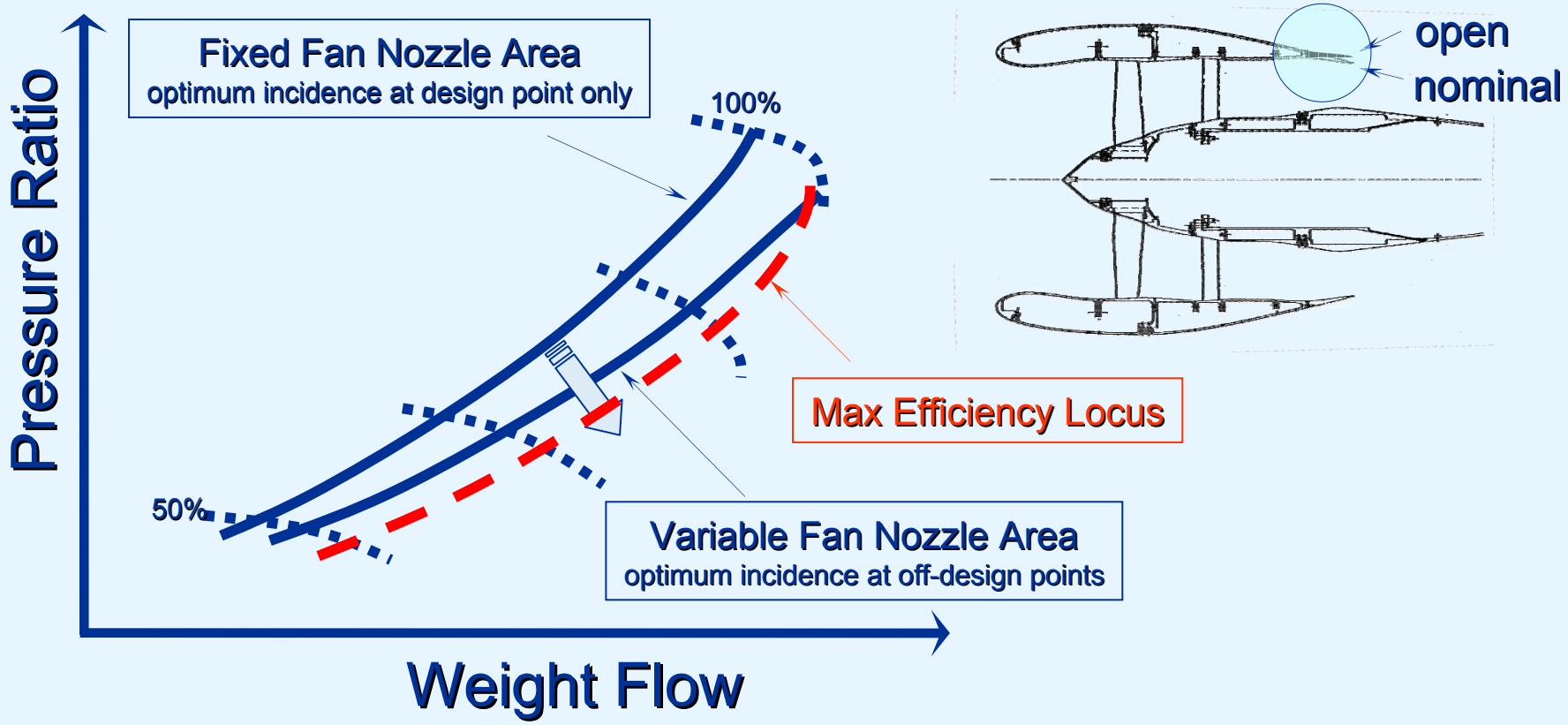
Status: The development of the 3D code is completed and the code is being validated using wind tunnel data.



State-of-the-Art Capability

Computed Solution for a 2D Benchmark Problem

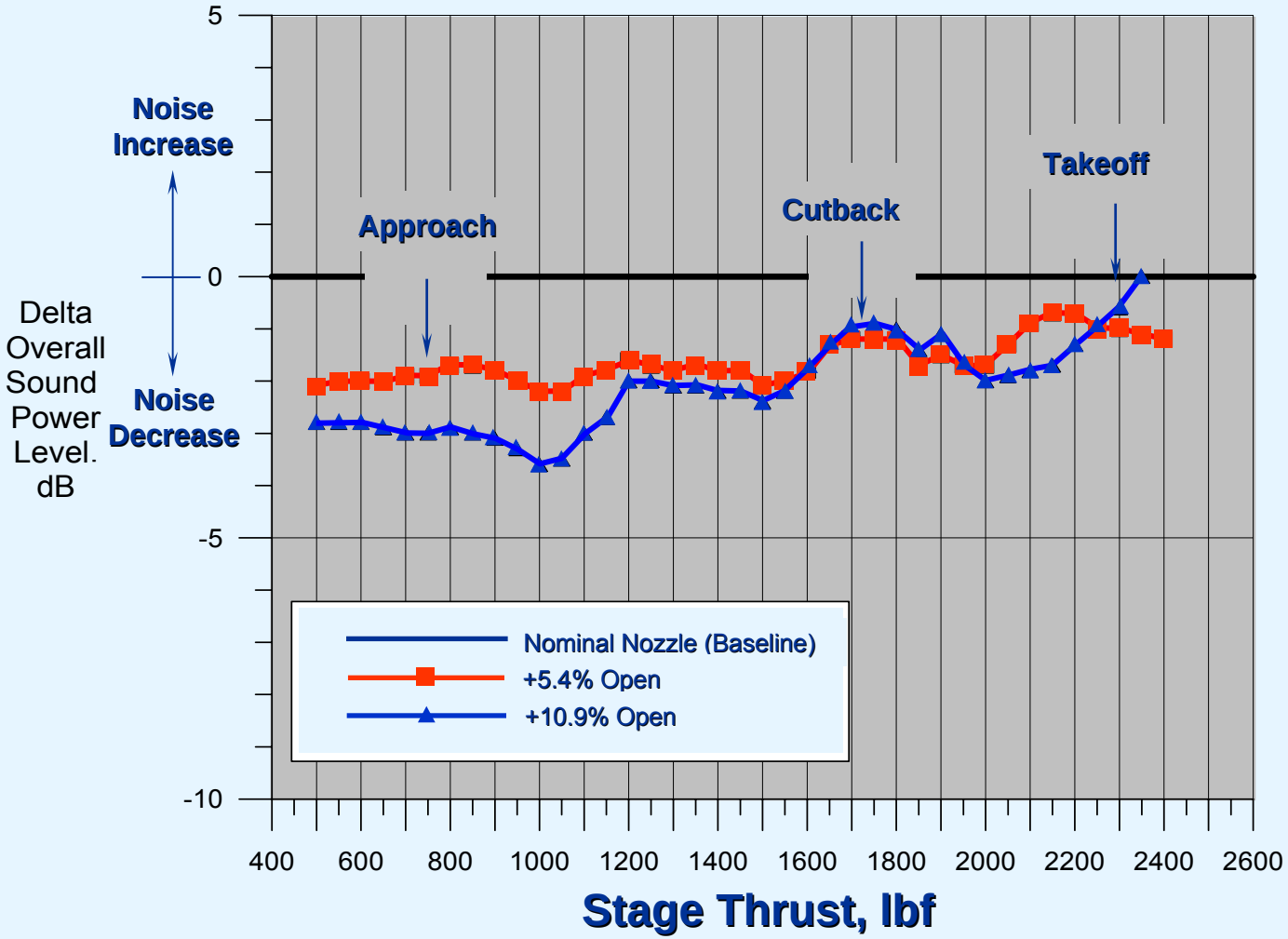
Fan Noise Reduction: Variable Area Nozzle



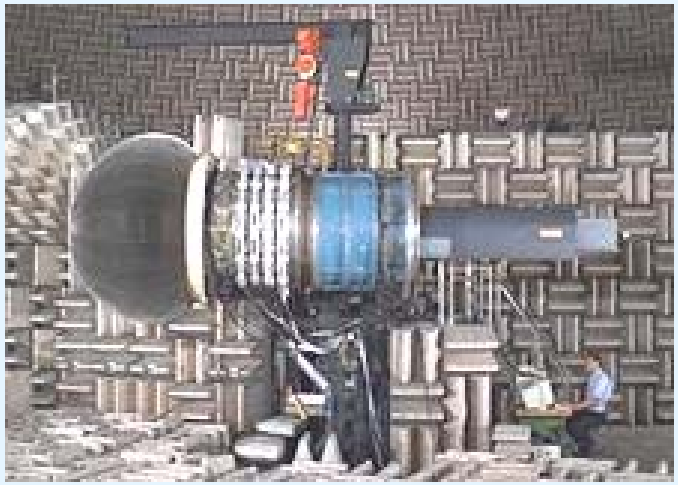
- **Motivation:** Improved Incidence → Less Noise
- **Benefits:** Reduced Noise / Enhanced Performance

9 x 15 Wind Tunnel Test Results

Noise Benefit: 2.0 dB (un-optimized)

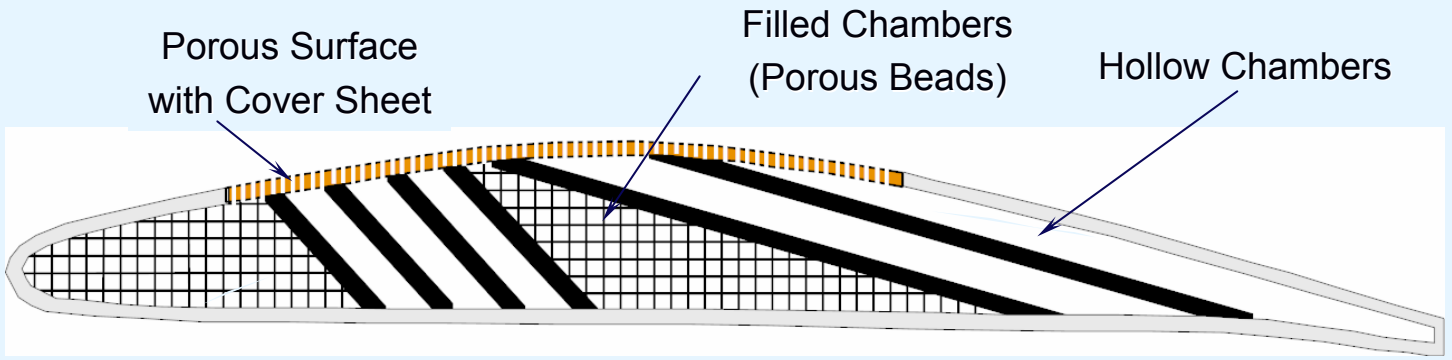


"Soft" Stator Vanes



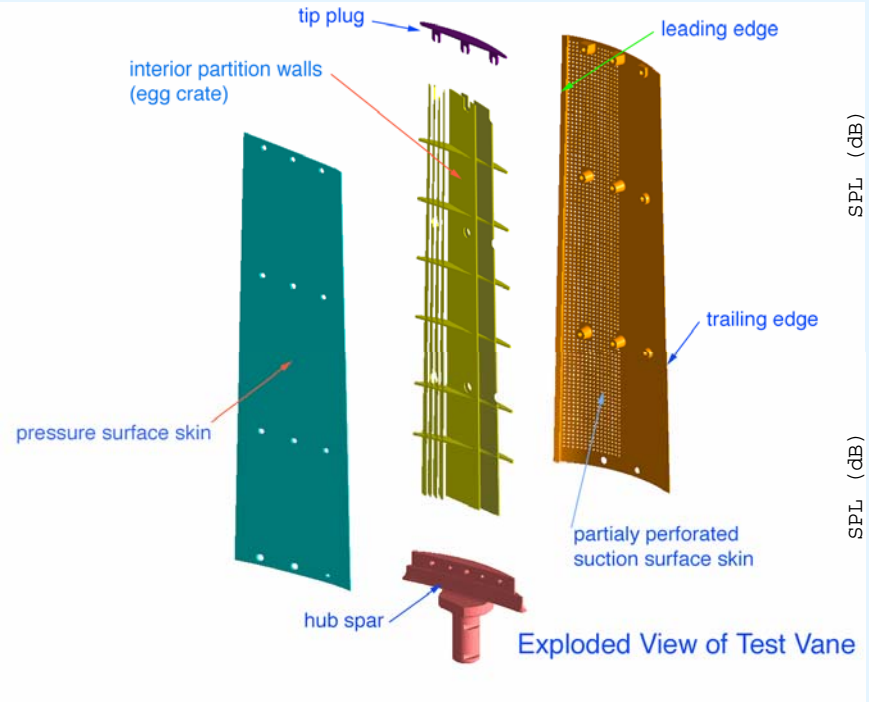
Testbed: **ANCF Fan Rig**

- **Motivation:** Reduce rotor-stator interaction noise by reducing vane pressure fluctuations
- **Benefits:** Passive System

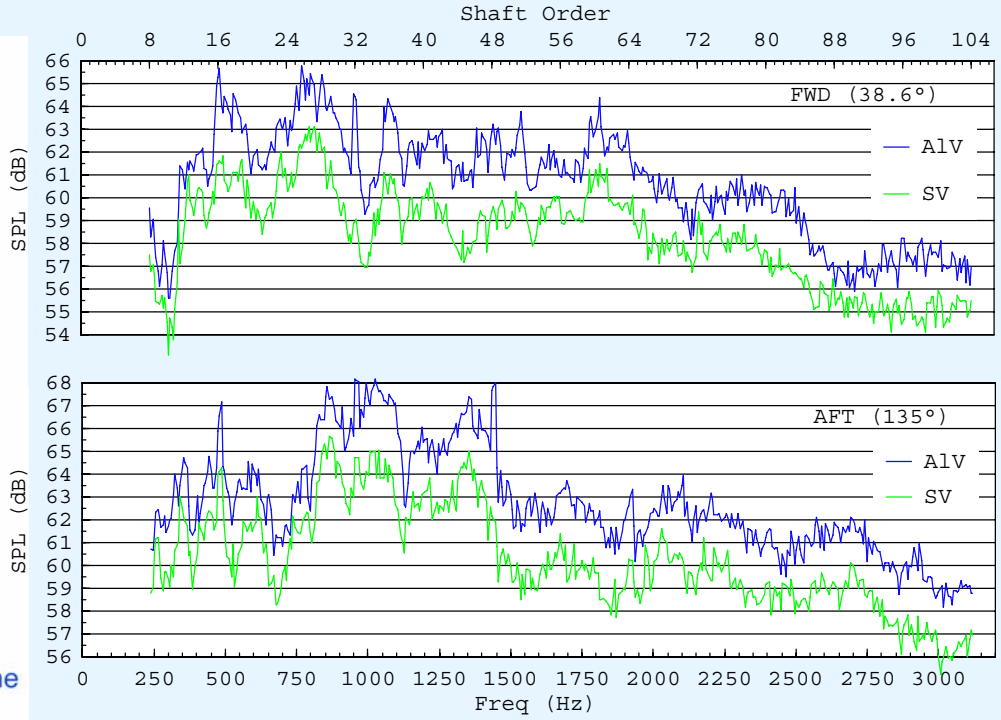


Sketch of Soft Vane Cross-Section

Low-Speed Fan Rig Results



Hardware



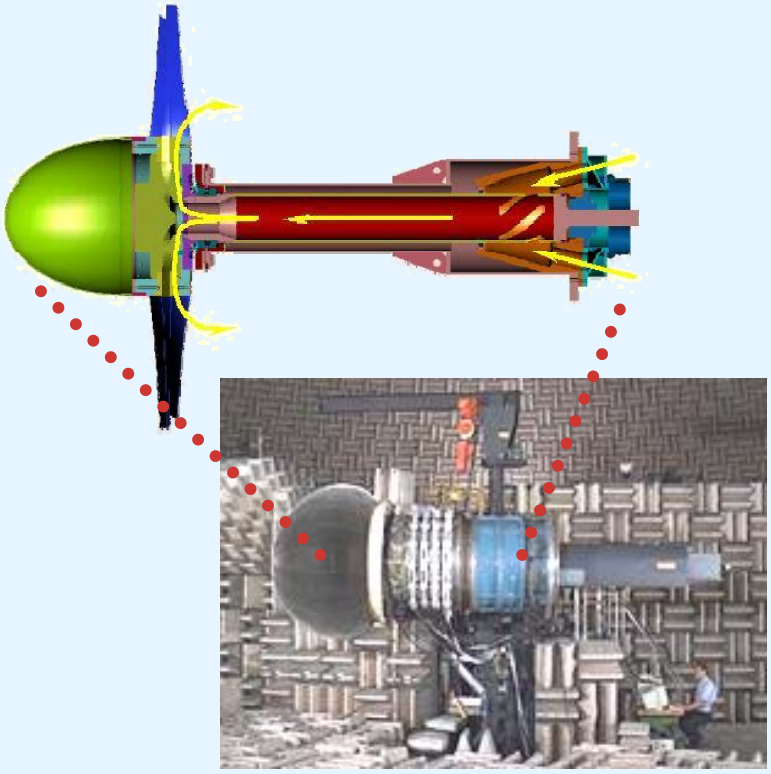
Fan Rig Data

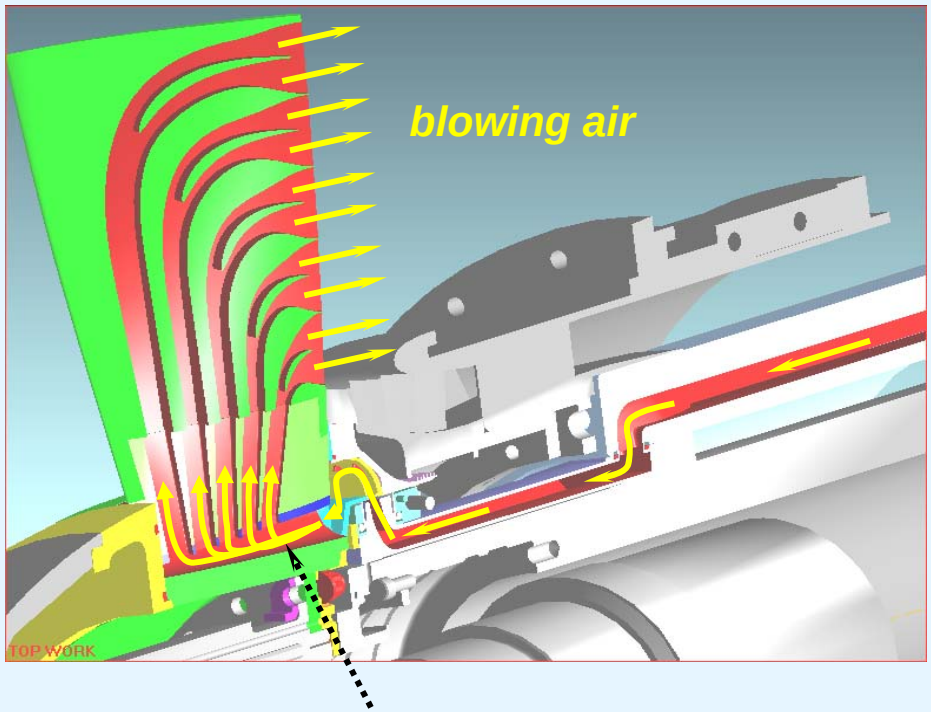
Measured Noise Benefit: 1.5 dB (un-optimized)

Trailing Edge Blowing

Benefits:

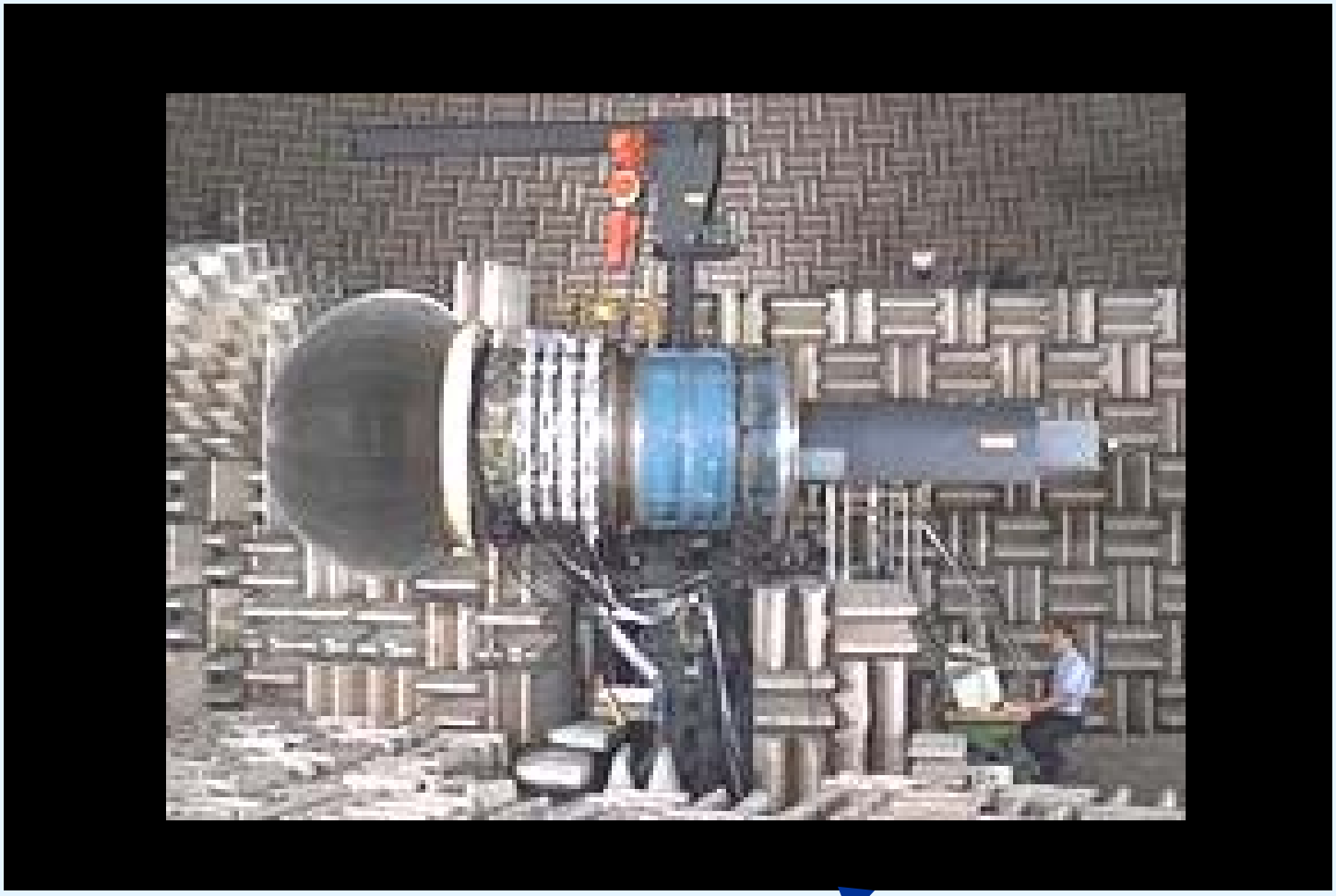
- Reduced Fan Noise





Testbed: **9x15 Wind Tunnel**

Trailing Edge Blowing – ANCF Demo

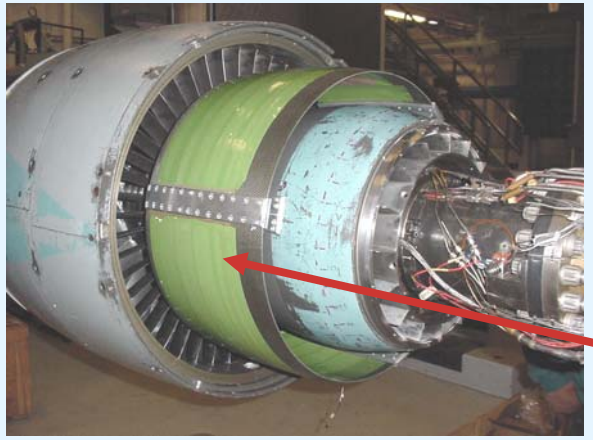


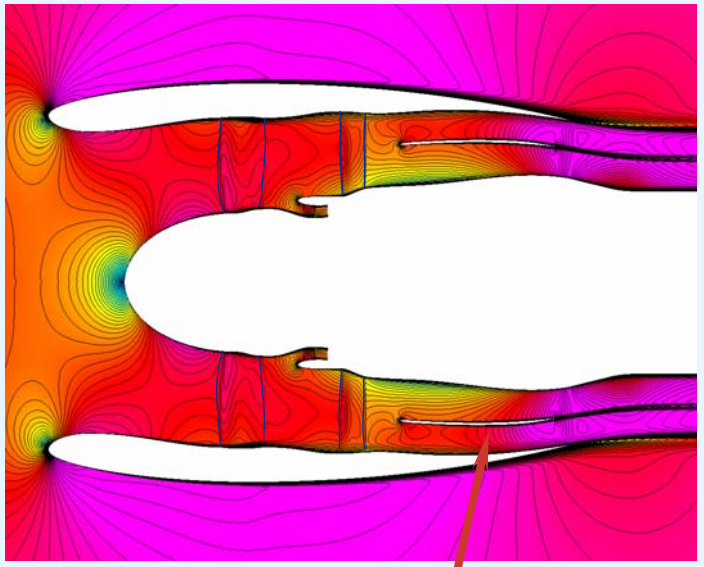
Click Here for Audio Demo

Fan Aft Duct Acoustic Splitter

Benefits:

- Reduced Fan Noise
- Passive System



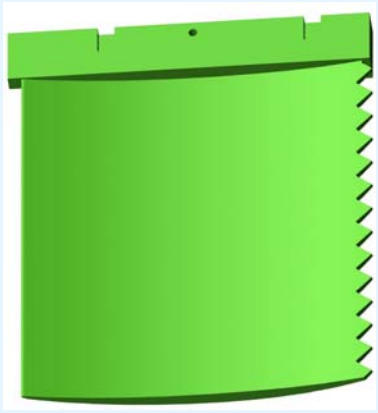


Treated Splitter

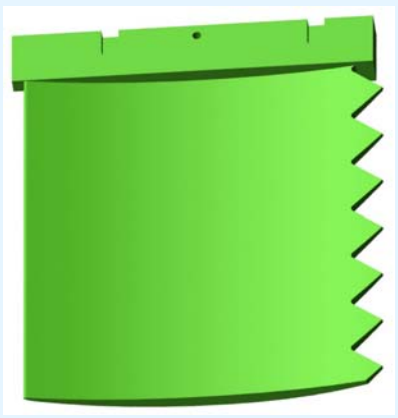
Test completed in the 9x15 Wind Tunnel

Fan Trailing Edge Chevrons (GE)

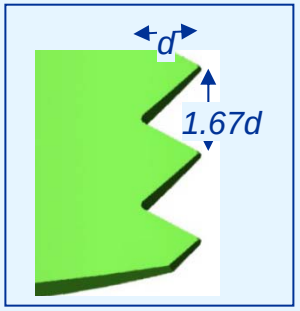
Baseline Blade



Half-inch Chevrons (*d* = 5%*c*)



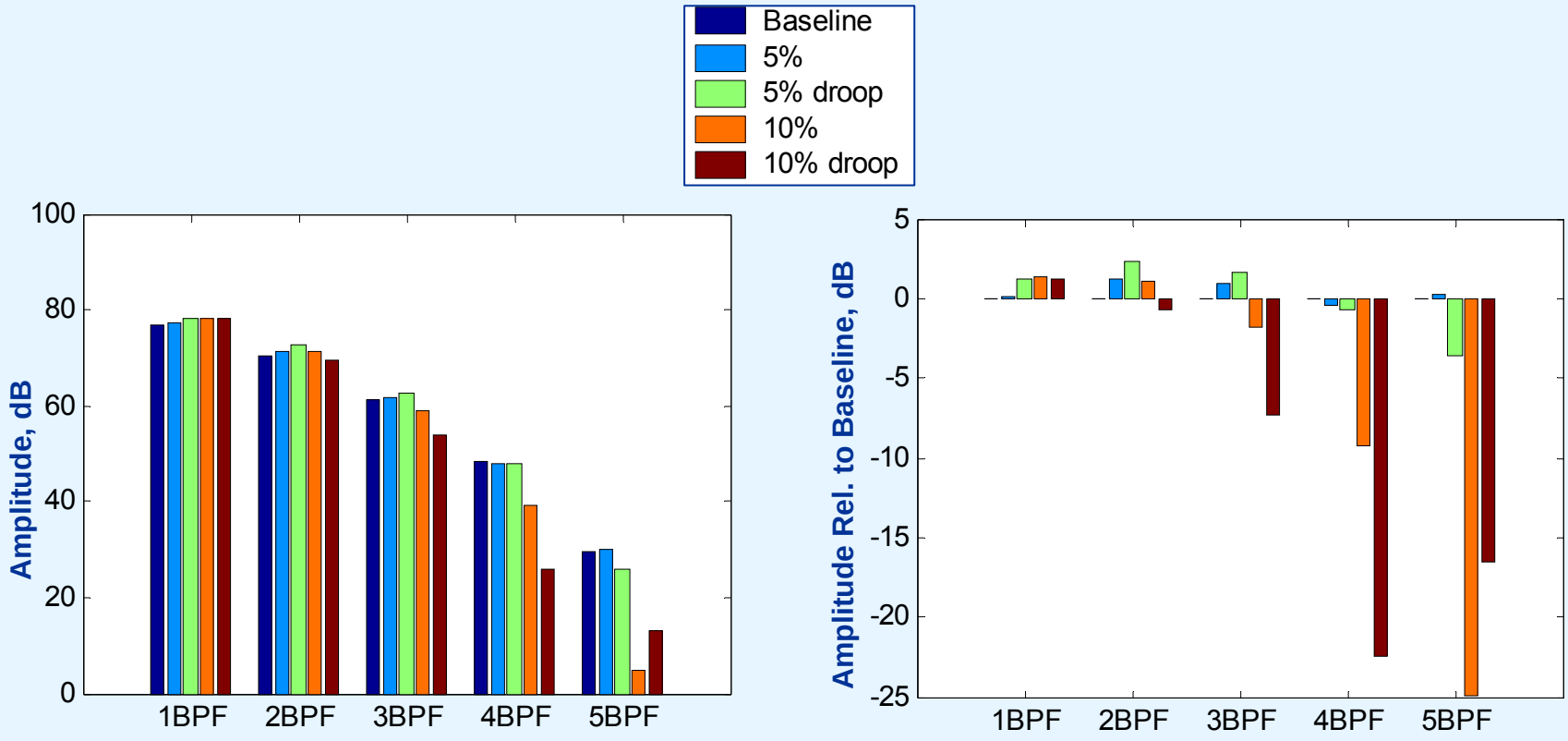
One-inch Chevrons (*d* = 10%*c*)



- **Motivation:** Enhance rotor wake mixing to reduce rotor-stator interaction noise
- **Benefits:** Passive System

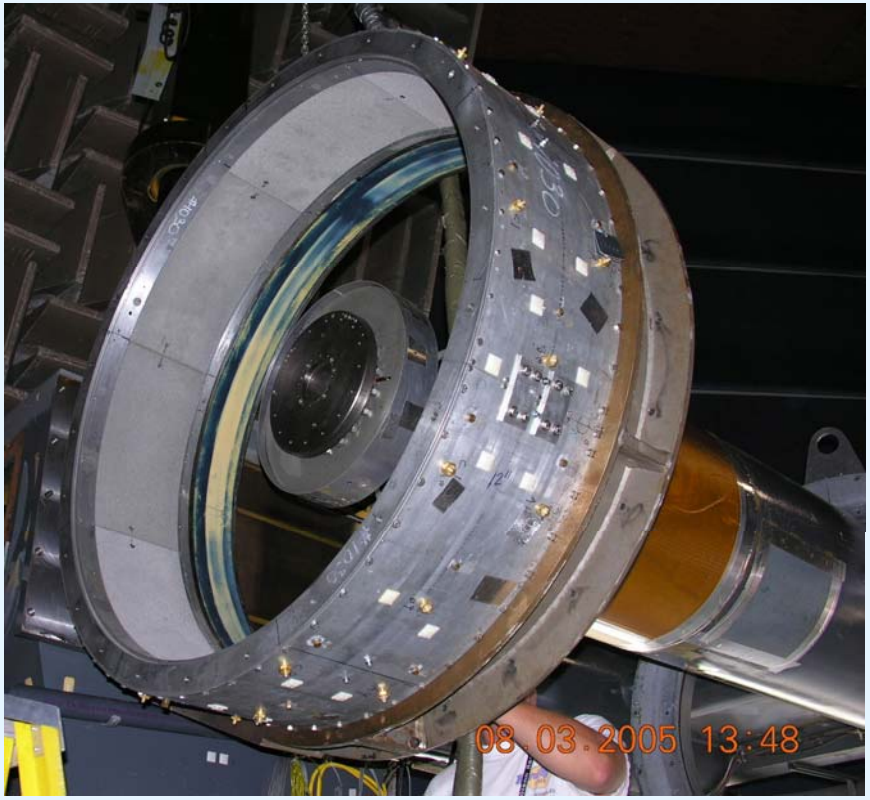
Fan Trailing Edge Chevrons - Cascade Test Results

Wake Harmonic Content



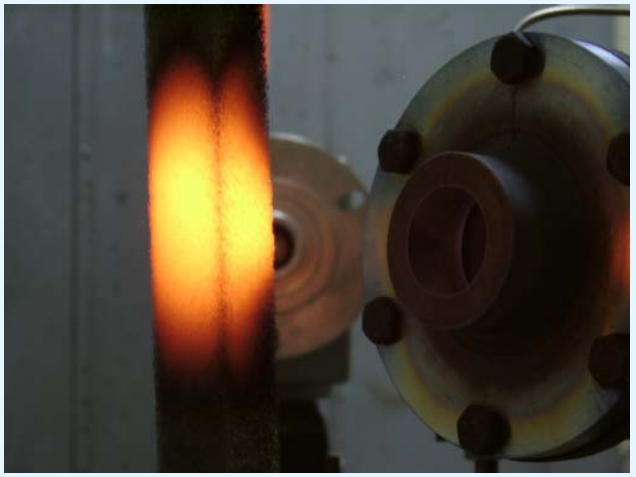
Potential for Tone Noise Reduction

Over-the-Rotor Acoustic Treatment
Haynes 25 Metal Foam

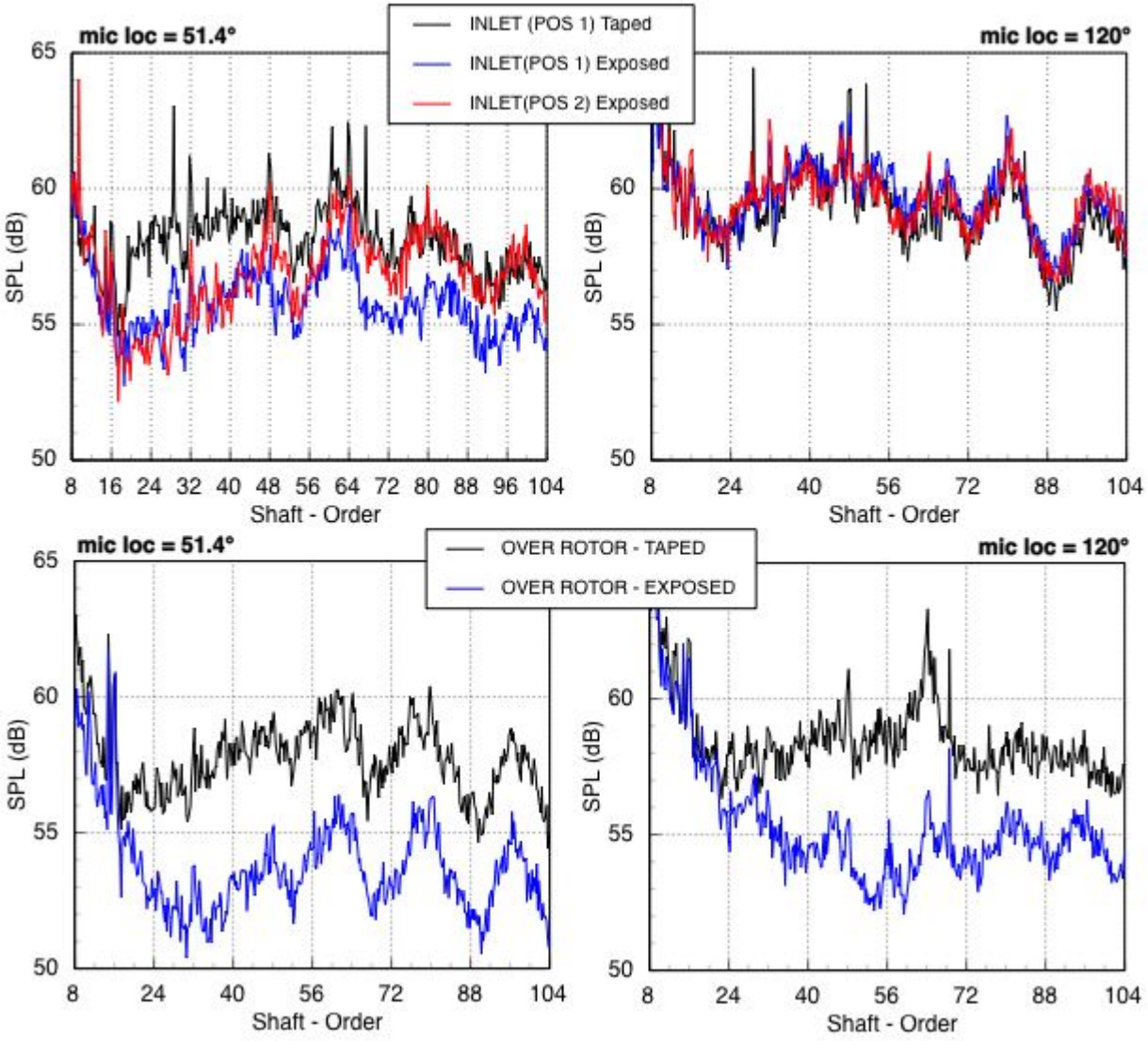


Haynes 25 Foam "Flight Worthiness" Tests

- **Flammability test: HA25 foam unaffected by 1000°C/30 min in a burner rig. Long life in oxidizing environment to at least 800°C.**
- **Immersion tests: HA25 foam specimens with a variety of size and shapes in various fluids such as water, skydroll, advanced hydraulic fluid and jet fuel (2 hr immersion + 2 hr ambient drying). Does not readily absorb fluids.**
- **Stress Tests : Mechanical properties surveyed, including compression, bending, tensile (w/face sheets). Can withstand expected mechanical loads.**



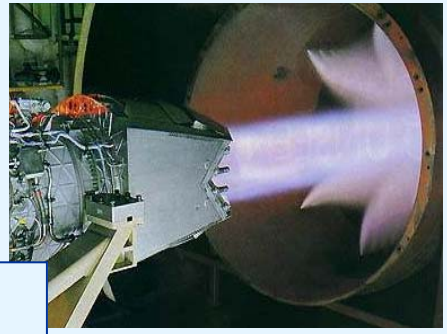
Haynes 25 Broadband Noise Spectra



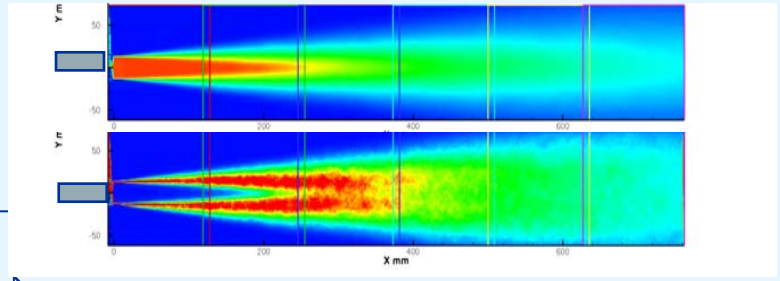
Jet Noise

Current Jet Noise Paradigm

Thrust

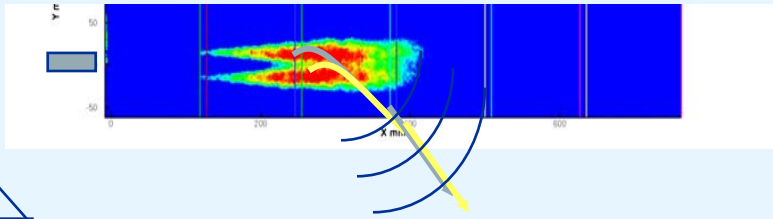


Flow Instabilities



Turbulence

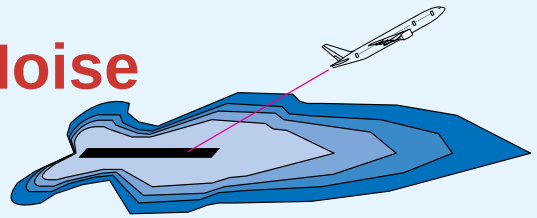
Energy Conversion?



Acoustic Source Strength

Propagation

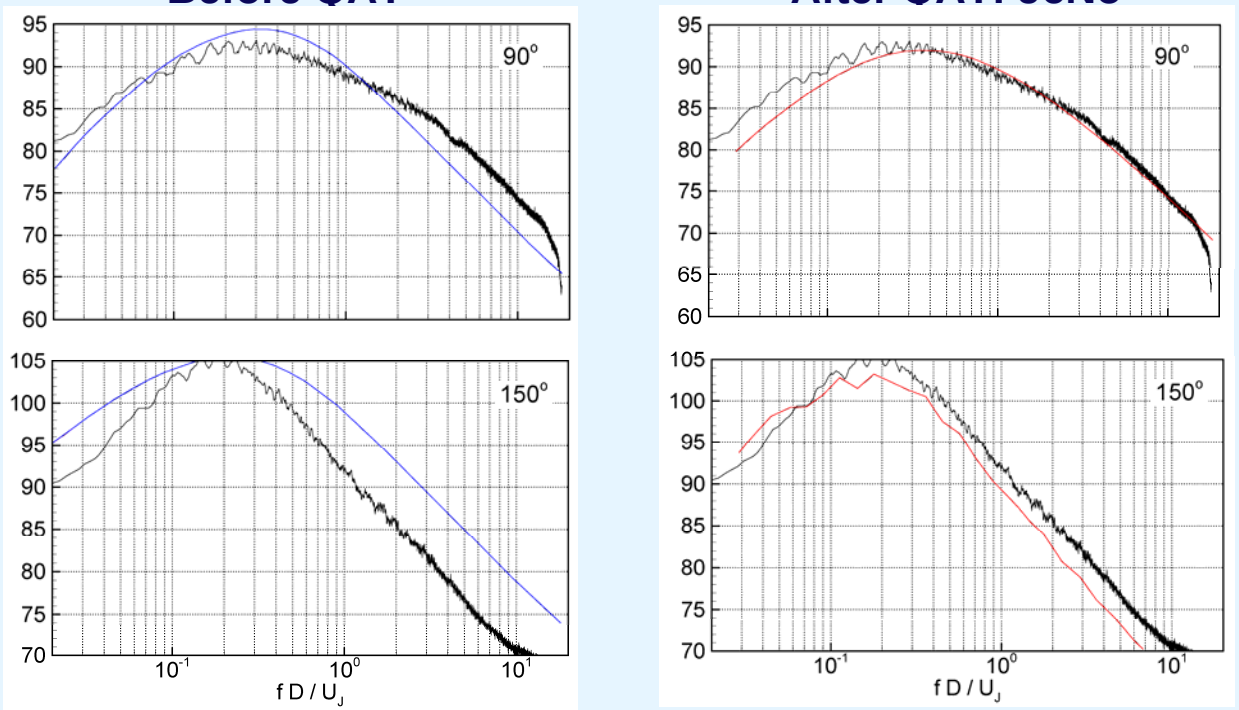
Noise



New Advanced Jet Noise Prediction Code: JeNo

- Improvements rolled into new prediction code
  - CFD Turbulence
  - Acoustic Source Models
  - Adjoint Green's Function Propagation

Before OAT | **After OAT: JeNo**



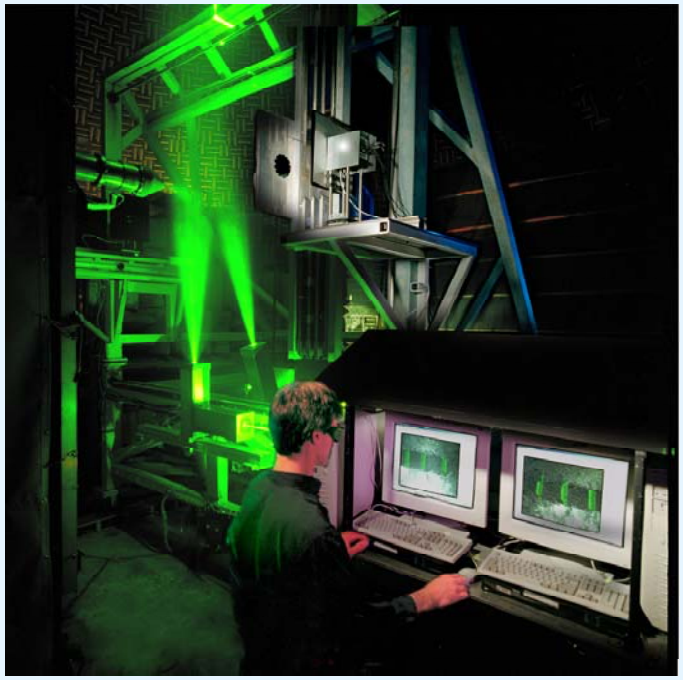
Ma=0.9 cold

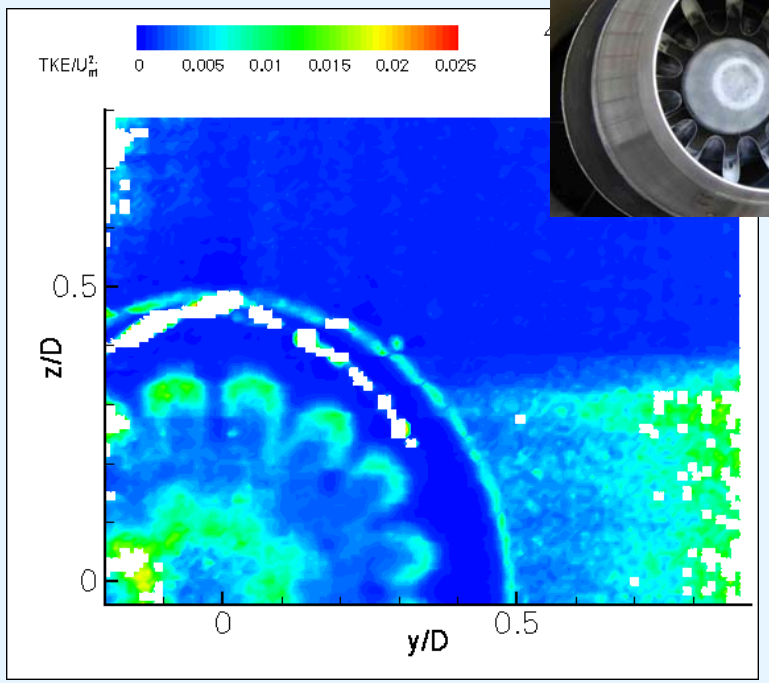
Good prediction of cold jet noise spectra at 90°

…and at aft angles!

Advancements in Turbulence Measurements

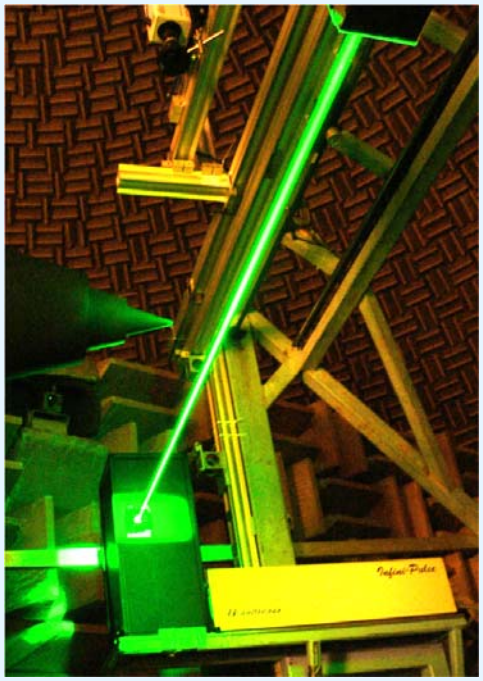
- Particle Image Velocimetry (PIV, *Wernet & Bridges)*
- Turbulence measurements in hot jets
- Two-point space-time velocity correlations in hot jets
- Cross-Stream Stereoscopic PIV





Time-Dependent PIV

Flow Direction ↓



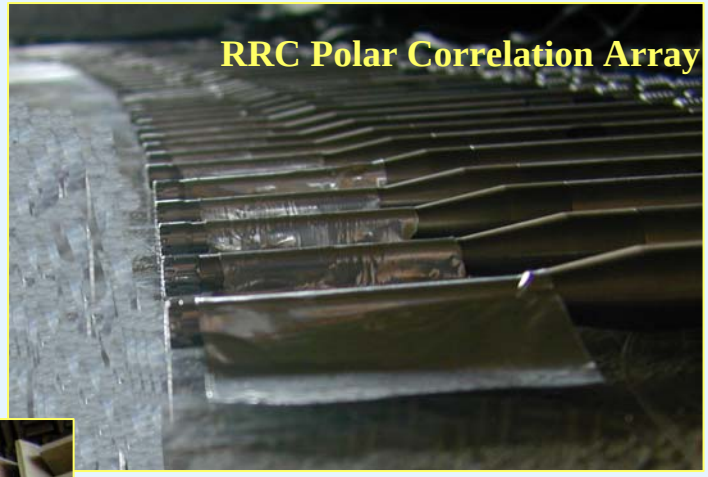
Time-dependent PIV setup in AAPL

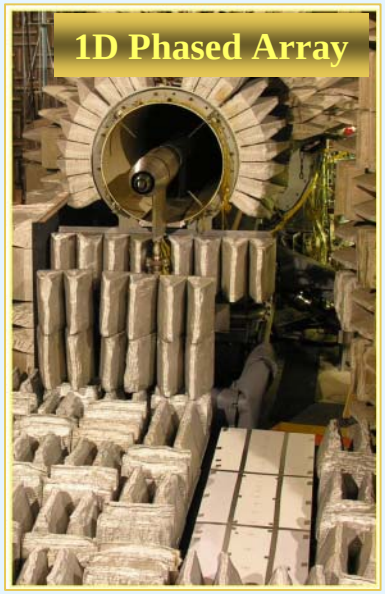
QuickTime™ and a
BMP decompressor
are needed to see this picture.

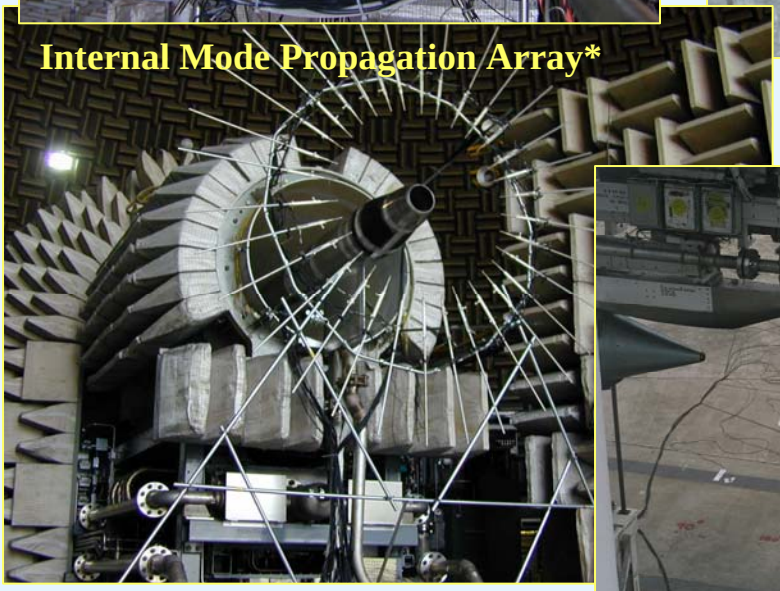
A 13x75mm region spanning from jet centerline through fan-core shear layer to outer fan stream shear layer is captured just downstream of plug of separate flow nozzle at takeoff conditions. Two components of velocity are captured at 150 points at 10kHz for 1.1 second (~0.1s shown here). Mean velocity subtracted to highlight unsteady flow.

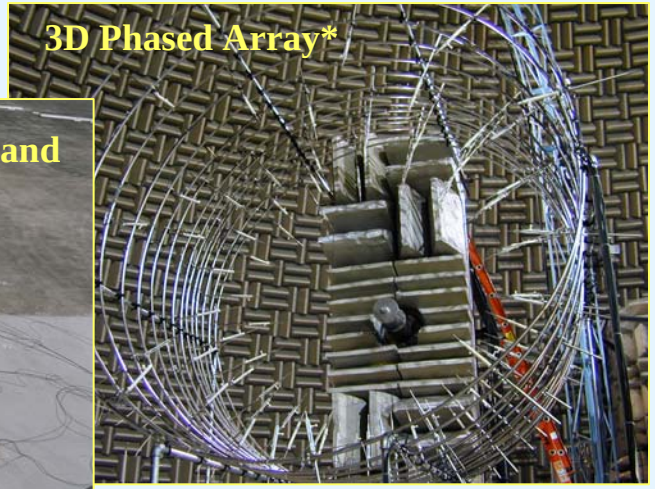
Click Here for Demo ↑

Advancements in Source Distribution Measurement



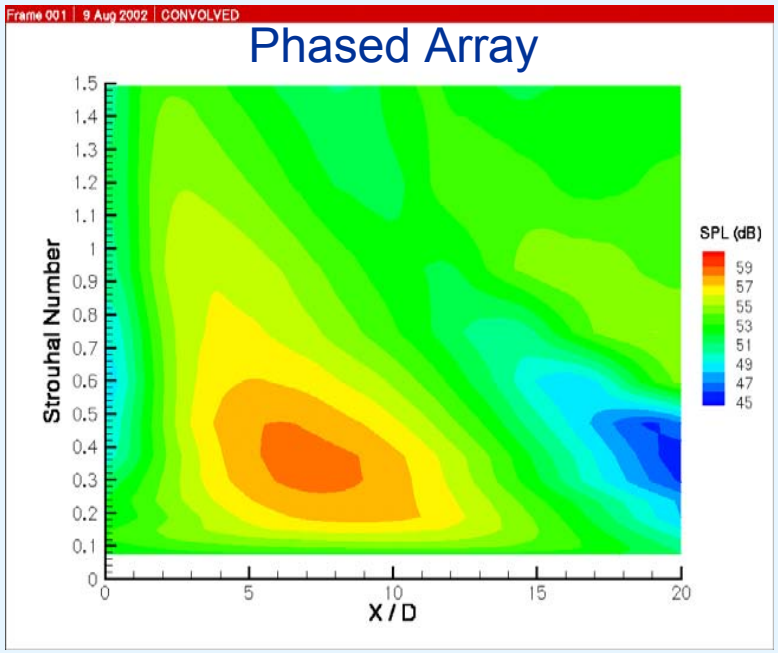


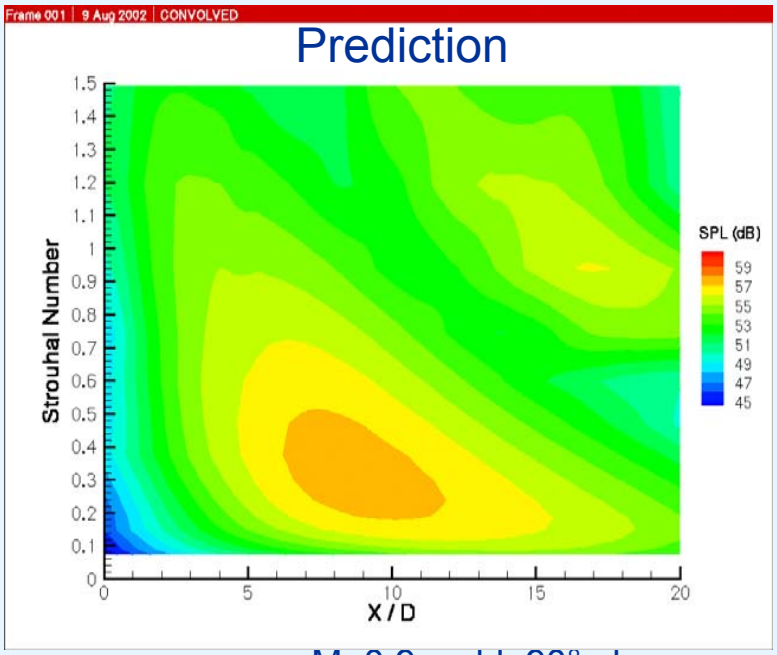




Jet Noise Source Distribution
Phased Array vs Prediction

- Phased array provides detailed diagnostic on prediction process
- Shows where noise reduction efforts should be concentrated

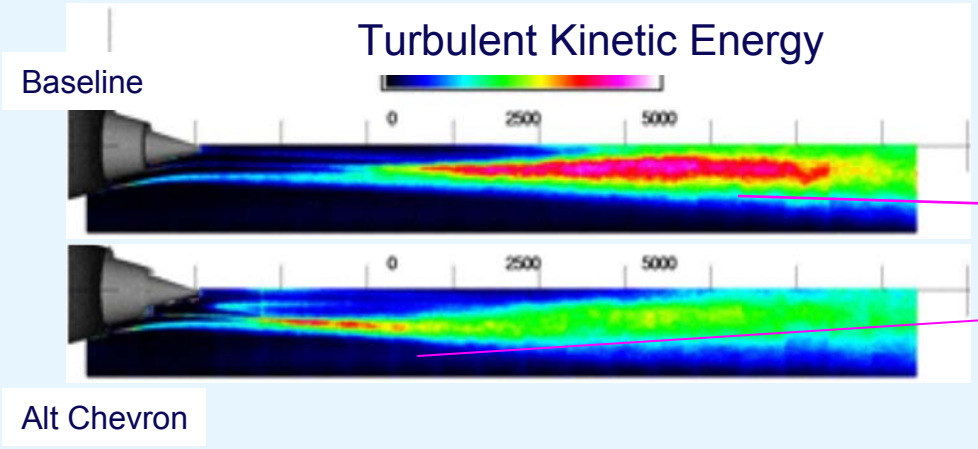


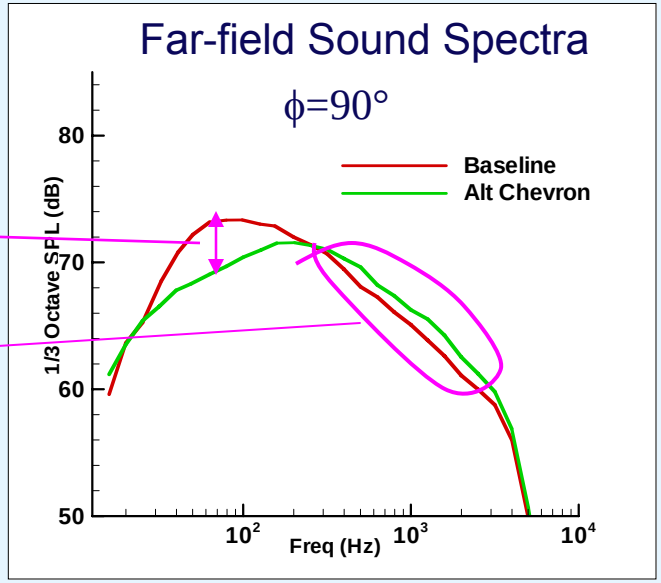


M=0.9, cold, 90° observer

Developing Mixing Enhancement Concepts

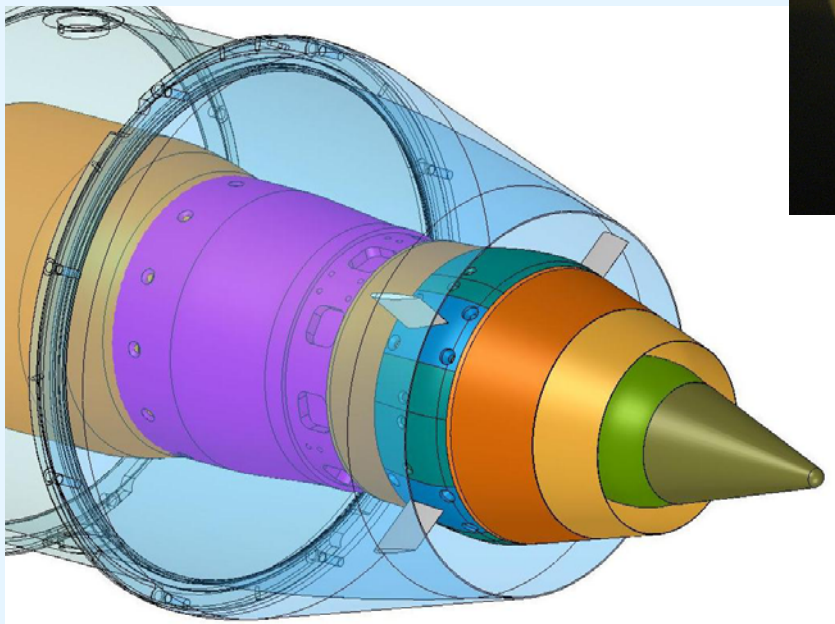
- Balance among competing factors:
  - decreased low frequency noise
  - increased high frequency noise
  - maintaining thrust performance



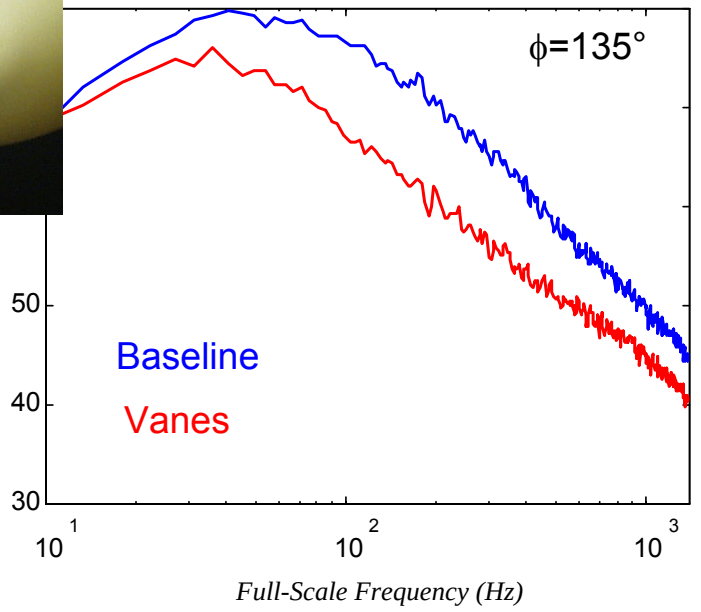


Flow Shielding Concepts

- Use non-axisymmetric plume and refraction to give favorable directivity
- Fan-stream vanes, wedge (U Cal Irvine), S-duct (LaRC)



UC Irvine Results



Validating Small Scale Results

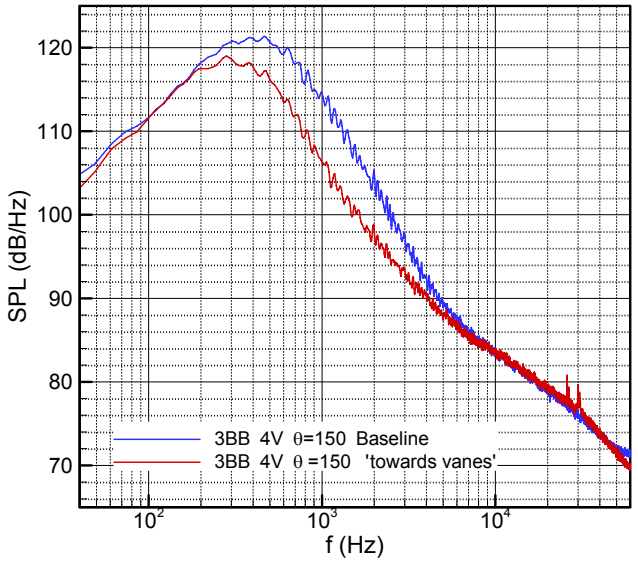
- Fan Vanes at Bypass ratio 5

θ = 150°

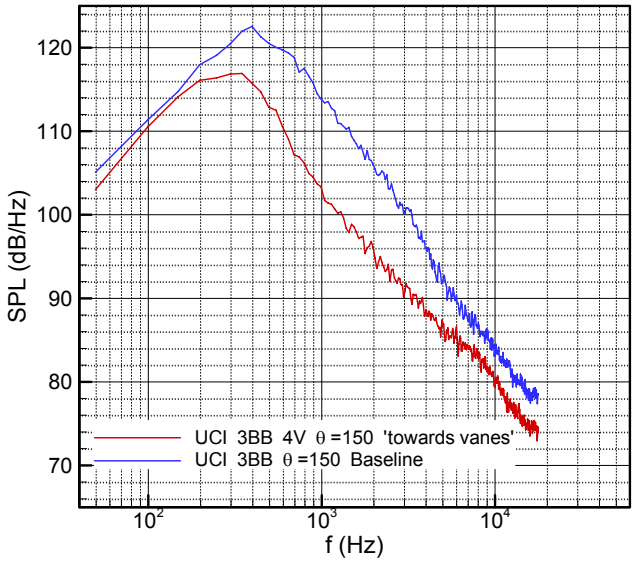
Baseline

Vanes

NASA GRC



UCI



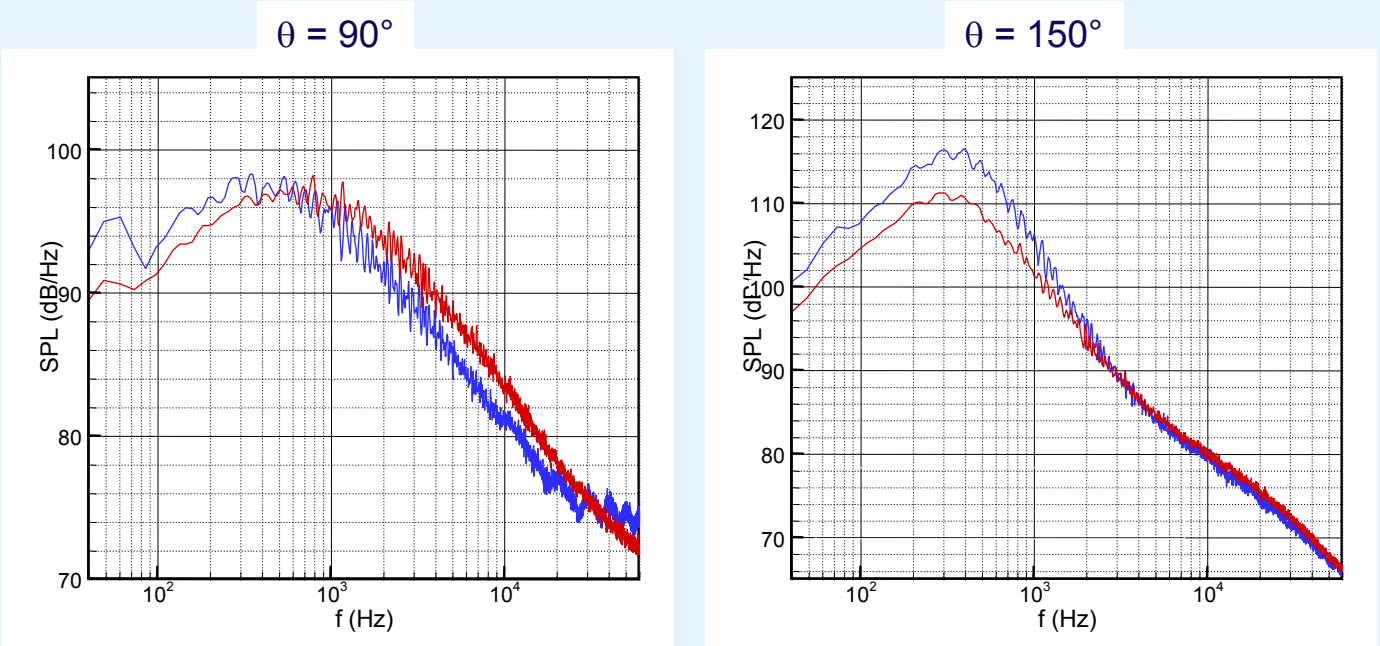
Fair confirmation for vanes at BPR 5

Extend Results to Higher BPR

- Fan Vanes at Bypass ratio 8

Baseline

Vanes



Benefit reduced for vanes at BPR 8

… 0.4 EPNdB reduction best achieved

Engine Noise and Future Opportunities

Jet Noise Reduction With Chevron Nozzles

Engine Noise Diagnostic Testing at Honeywell

Engine:

Honeywell HTF7000
Tech Demonstrator

2005/06 Engine Tests Include:

- Internal flow measurements
- Microphone arrays to map engine acoustic field
- Fan noise modal measurements
- In-situ impedance measurement

Noise Reduction Technologies:

- Forward-Swept Fan
- Advanced acoustic liners

Small Demonstrator Supports Business & Regional Jet Applications

Design of Low Noise Engine Initiated at P&W

Ultra-High Bypass "Advanced Geared Turbofan"

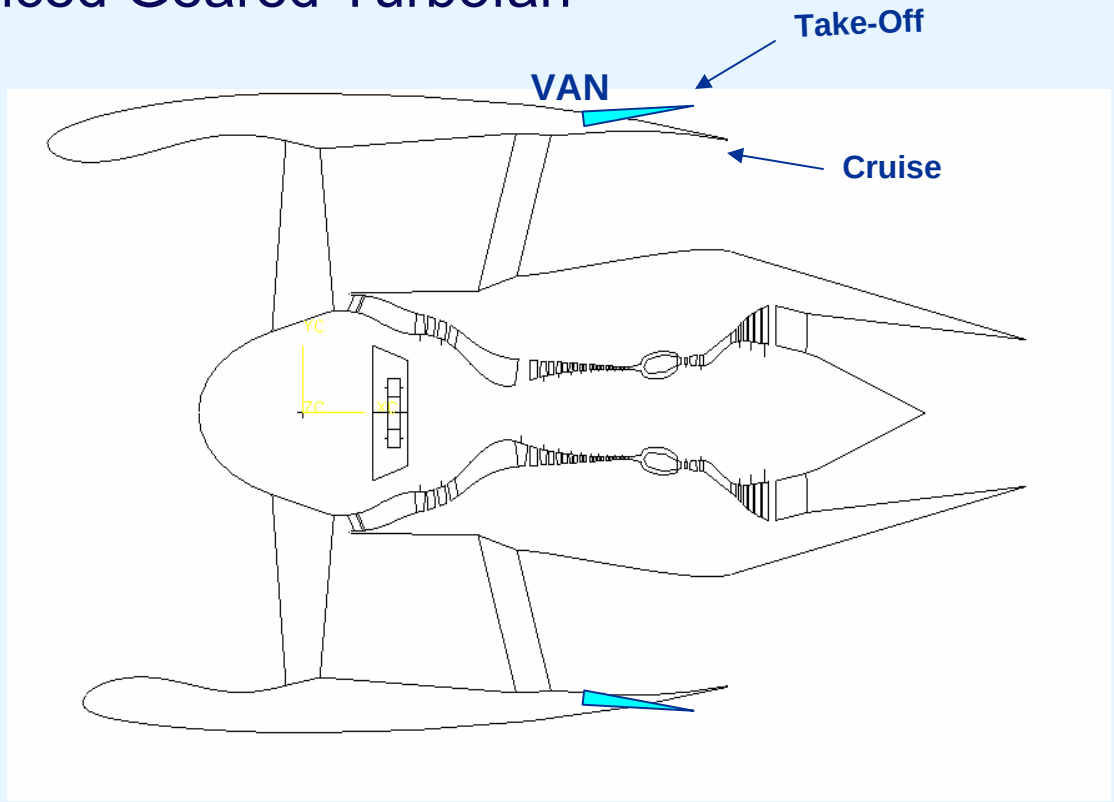
Low Noise Because of:

- Low fan tip speed
- Low jet exhaust velocity

Enabling Technologies:

- Fan drive gear system
- Variable area fan nozzle

Additional Noise Reduction Advanced Technologies



Wind Tunnel Fan Operability Test Planned for 2006

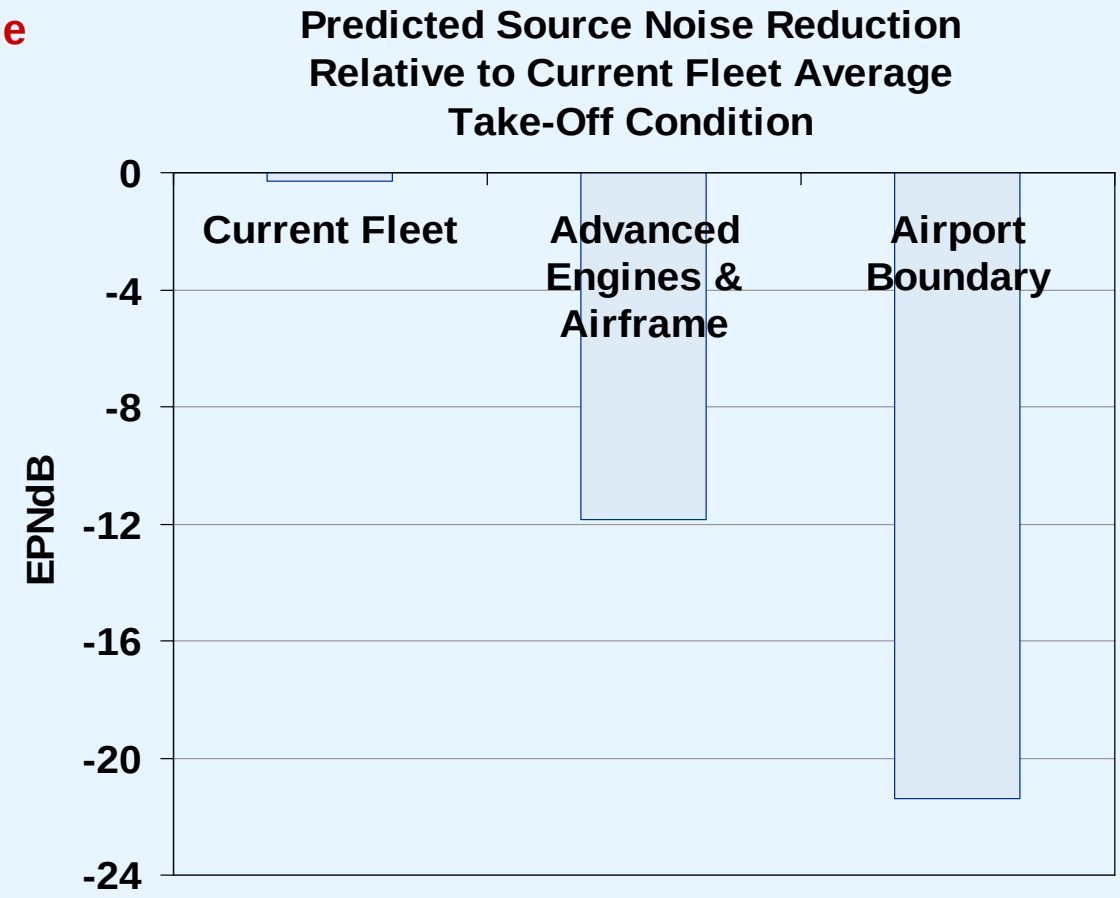
Quiet Airplanes of the Future - Takeoff

Advanced Engines & Airframe

- Lower Fan Tip Speeds
- Lower Jet Exit Velocities
- Variable Area Nozzle
- "Soft" Fan Stator Vanes
- Fan Trailing Edge Blowing
- Bypass Acoustic Splitter
- "Toboggan" Landing Gear Fairings
- Continuous Mold Line Flap
- Slat Cove Filler

Airport Boundary

Projected level required for objectionable noise to be contained within airport boundary.



Click on picture to play sound demo:

Inlet Aft

Quiet Airplanes of the Future - Approach

Advanced Engines & Airframe

- Lower Fan Tip Speeds
- Lower Jet Exit Velocities
- Variable Area Nozzle
- "Soft" Fan Stator Vanes
- Fan Trailing Edge Blowing
- Bypass Acoustic Splitter
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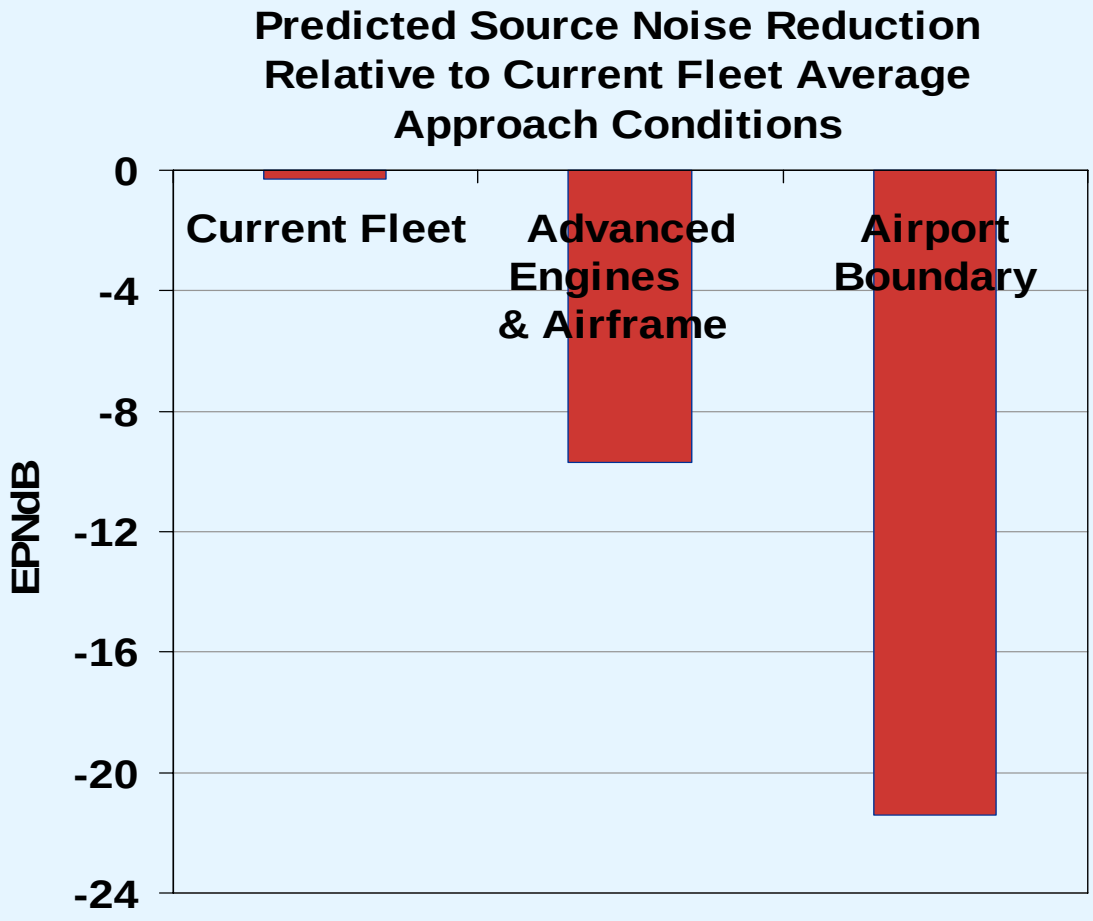


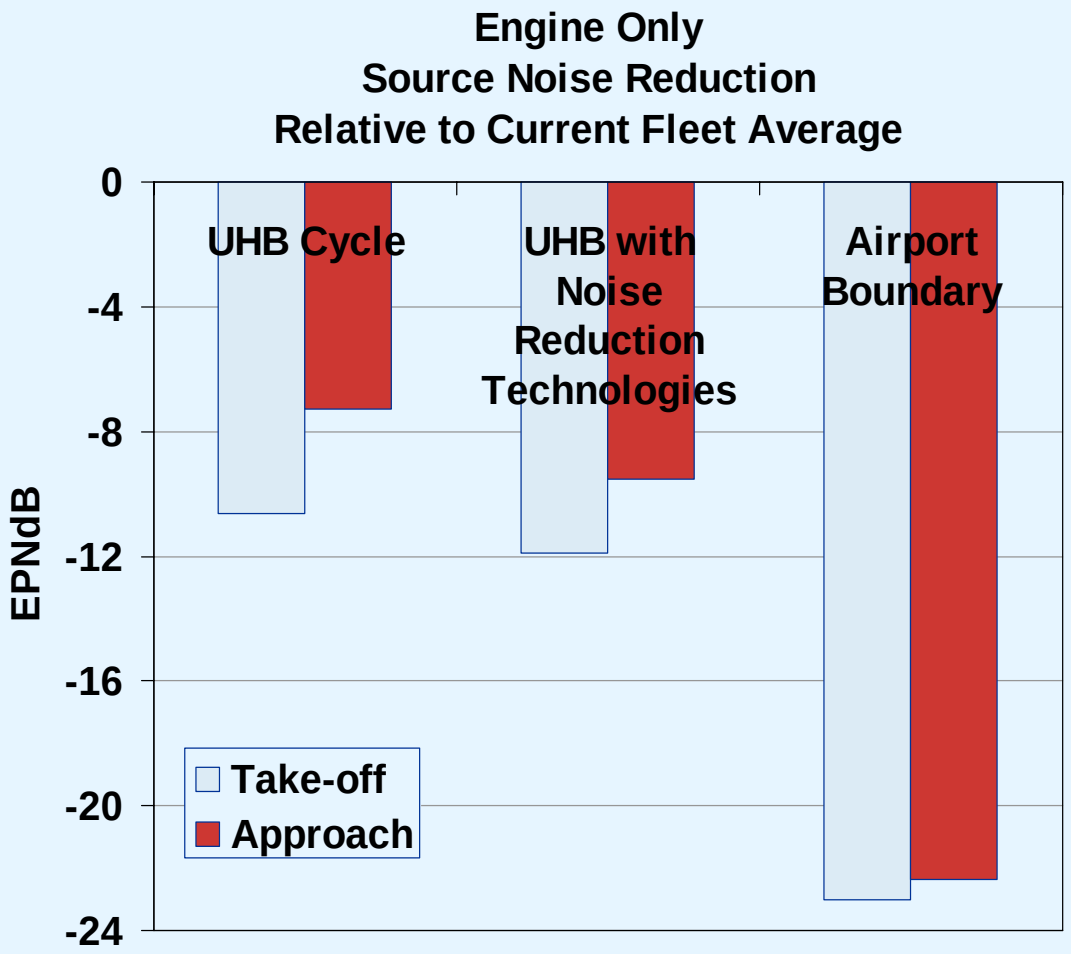
Click on picture to play sound demo:

Inlet Aft

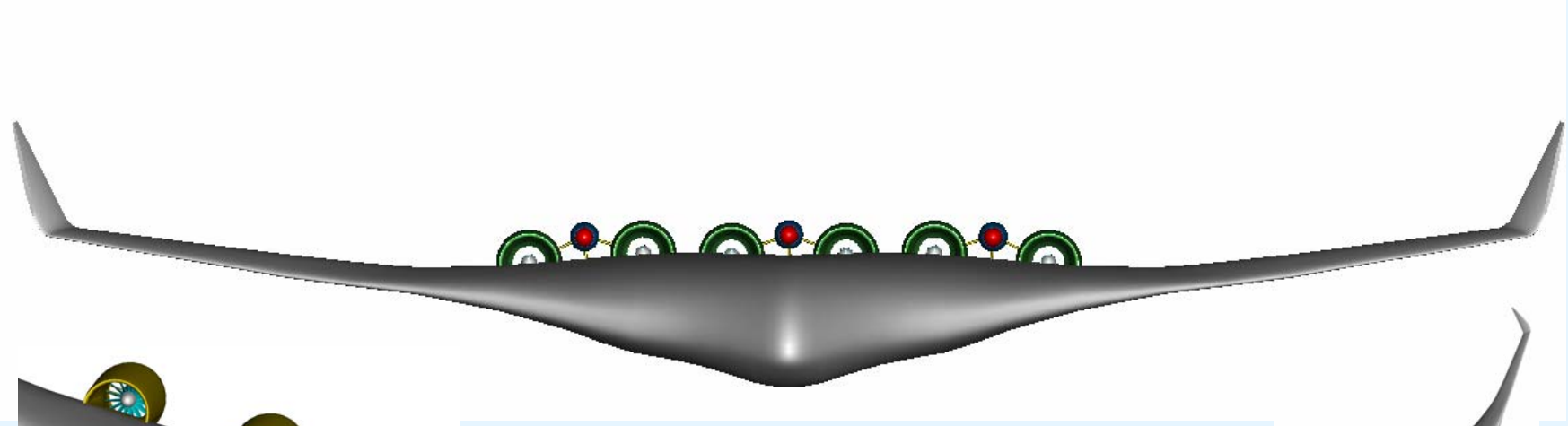
Quiet Airplanes of the Future

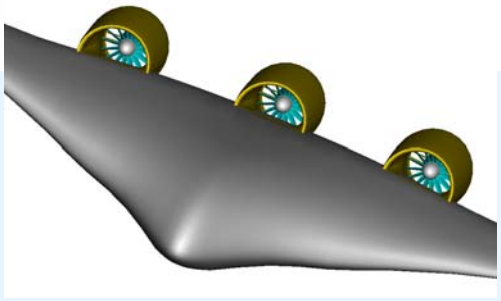
Engine Cycle versus Noise Reduction Technologies

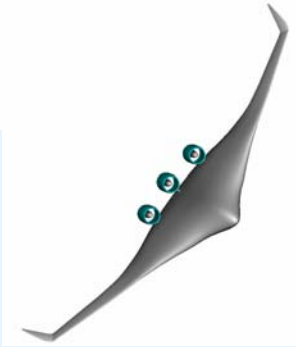
- **Significant noise reduction can be achieved with the combination of engine cycle change and advanced noise reduction technologies**
- **Further cycle changes will be difficult**



Dual Fan – Conceptual Applications

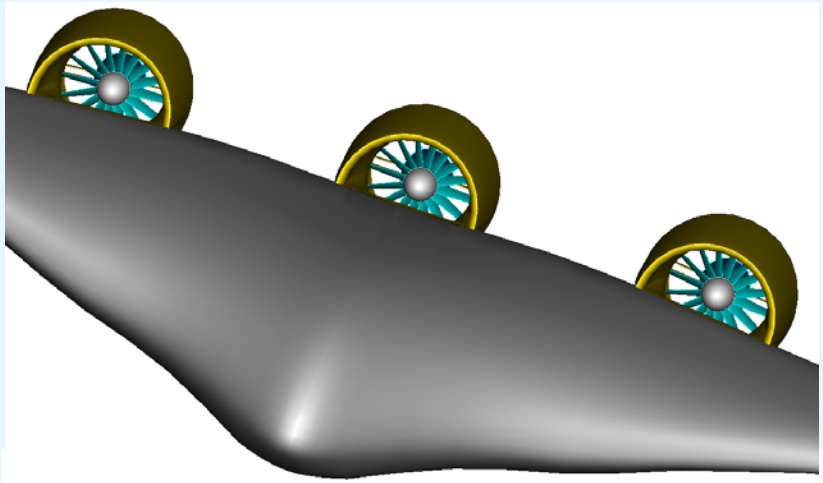


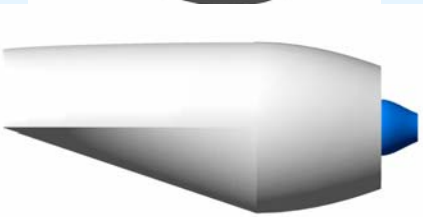


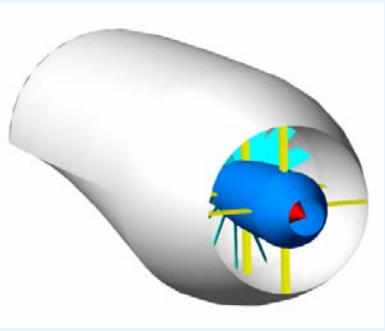


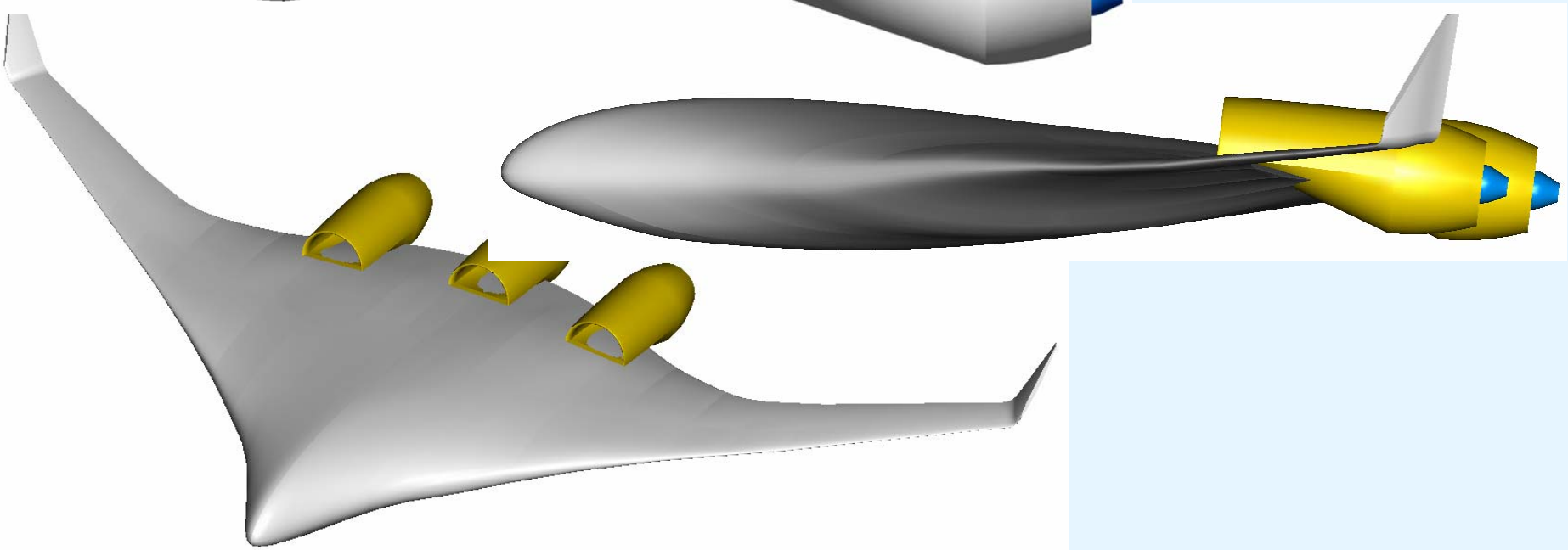
Single Fan On Blended Wing Body (BWB)

Fan Diameter	154.2”



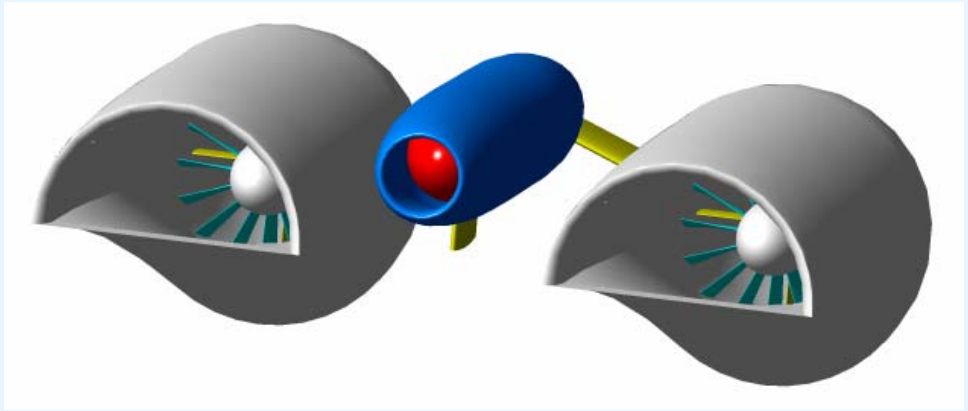


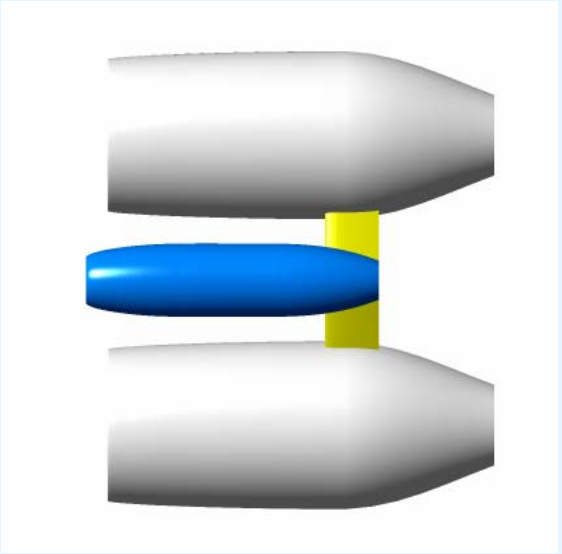


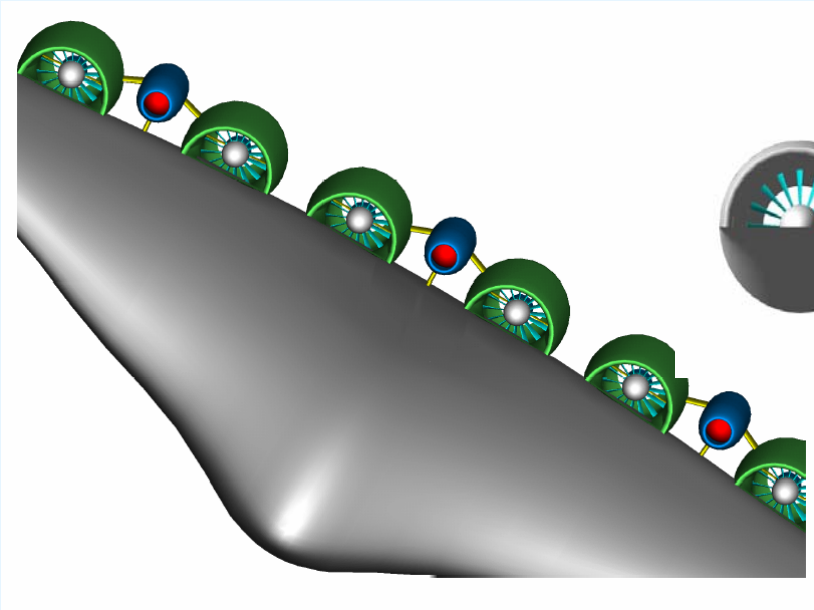


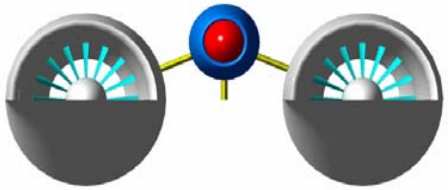
Dual Fan On Blended Wing Body (BWB)

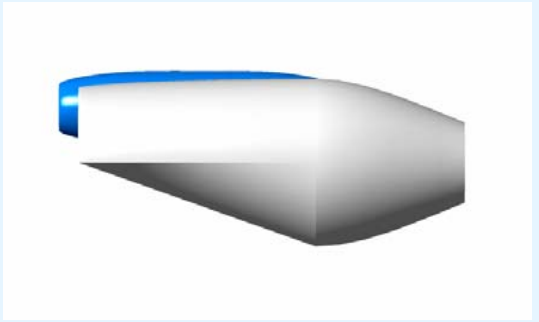
Fan Diameter	105.1”











Summary

- Engine noise reduction research has concentrated on fan and jet components, many ideas have been investigated over the past 10-15 years.
- Source diagnostic experiments and advanced flow/acoustic measurement methods have been key to understanding noise generation, developing prediction tools, and identifying noise reduction strategies.
- Significant engine noise reduction will be achieved with the introduction of Ultra-High Bypass Ratio engines (low-speed fans, low jet velocities), noise reduction technologies will be more effective.
- We hope to continue our strong partnerships with industry and universities, significant progress has been made working together through programs like AST and QAT.

Backup Charts

Progress in Turbofan Engine Noise Research Over Past 10 Years

Fan Noise

- Prediction for wake/stator interaction based on 3D sources with realistic mean flows
- Improvements in source description due to better understanding of wake disturbances
- Reduction methods concentrate on stators, experiments quantify rotor alone source strength
- Active noise control successful for multiple tones, but require complex/expensive integration
- Duct propagation methods validated for axisymmetric nacelles

Jet Noise

- Prediction improvements from CFD/RANS and acoustic source/propagation methods
- Significant reduction for separate flow nozzles using chevron mixing devices
- Improved space-time correlations with non-intrusive unsteady flow measurements (hot jets)
- Phased array source identification methods

Core Noise

- Limited progress due to emphasis on fan and jet (dominant sources)
- Improved empirical models using engine data
- Combustion noise reduction using tailcone Helmholtz resonators

Engine System Noise

- Most significant noise reduction comes from newer engine cycles with lower fan tip speeds and lower jet exhaust velocities (higher bypass ratio engines)
- Limited progress in system noise assessment with emphasis on component technologies

Unsolved Problems for Engine Noise Research

Generic

- LES/DNS methods for source prediction, hybrid methods => Establish NASA COE across centers
- Source identification methods for internal/external flows (phased arrays, etc.)
- Trailing edge noise generation physics
- Turbulence measurement and prediction methods for hot high-speed flows

Fan Noise

- Physical understanding and modeling of rotor generated noise sources
- Prediction methods for supersonic fan tip speeds, non-linear prediction method for MPT's
- Reliable rotor transmission/reflection model
- Physical/computational predictions for advanced acoustic liners and impedance measurements
- Broadband noise prediction

Jet Noise

- Hot jet source prediction including mixing and shock noise
- Noise reduction strategies without reducing jet exhaust velocities

Core Noise

- Non-empirical prediction methods for combustors, compressors and turbines
- Source identification methods when other sources like the fan and jet dominate

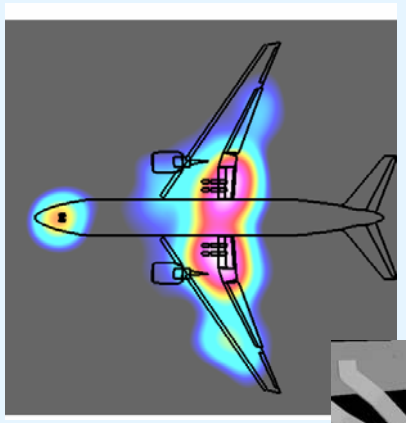
Engine System Noise

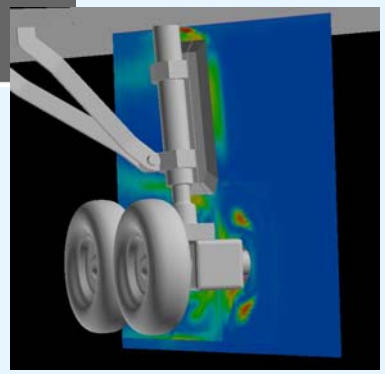
- Noise propagation methods for complex geometries and shear flows
- Unified component prediction method (start with combining fan/jet source models)
- Reliable data base for engine noise sources particularly for newer engines
- Noise reduction strategies through engine placement studies and advanced cycles

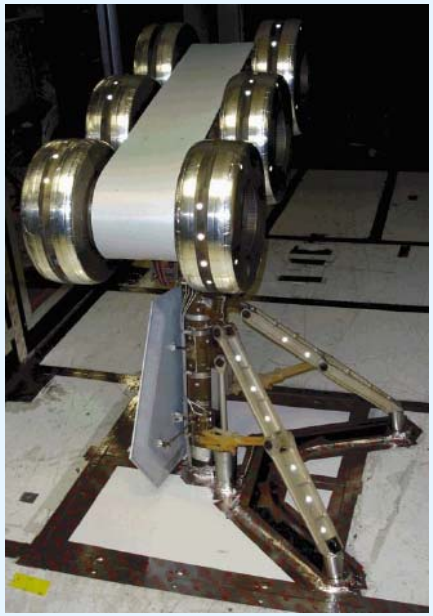
“Toboggan” Landing Gear Fairings

Benefits:

- Reduced Gear Noise



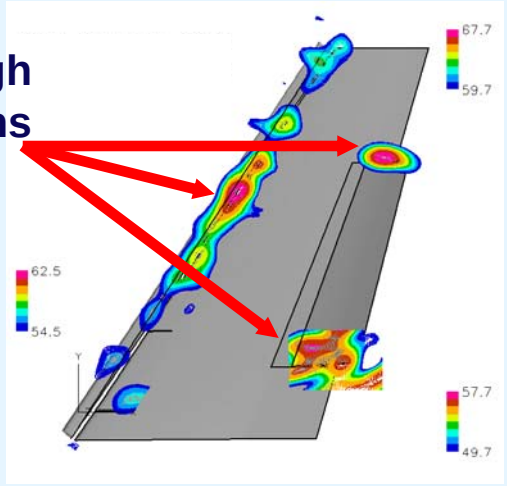




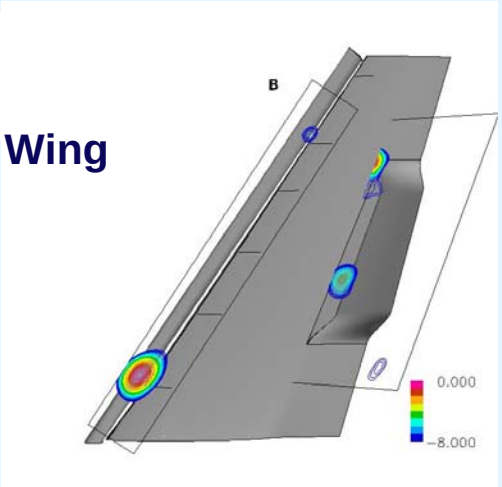
Flight Test In August 2005

Continuous Line Mold Flap & Slat Cove Filler

Baseline: High Noise Regions



Low-Noise Wing



Benefits:

- Reduced Flap and Slat Noise